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Assessing the development of high school chemistry students' conceptual and visual understanding of dimensional analysis via supplemental use of a proprietary interactive software program

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ASSESSING THE DEVELOPMENT OF HIGH SCHOOL CHEMISTRY STUDENTS' CONCEPTUAL AND VISUAL UNDERSTANDING OF DIMENSIONAL ANALYSIS VIA SUPPLEMENTAL USE OF A PROPRIETARY INTERACTIVE SOFTWARE PROGRAM

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DEDICATION

To my grandmother, Louise Elizabeth Woolford Pinder (April 24, 1921-May 15, 2009), who passed away while I was collecting data.

Ten Seeds
By Erin Leigh Pinder

My grandmother was given ten seeds and she placed them gingerly in the ground.
She cared, watered, nurtured, and loved the seeds until they began to grow.
She fed them with nutrients to ensure a strong and fruitful harvest,
And showed them it was okay to enter the world.
She never fret or was discouraged by hard winter and dry summers,
She kept on watering her seeds.
Now she has a full garden with three times of what she started with.
She is truly reaping what she sowed;
When she looks out her window she reaps the kindness she sowed,
The strength she sowed and the wisdom that she sowed.
Each day as her harvest grows and gets bigger and more fruitful
We have YOU to thank Grandma, for all the work done,
When you planted those ten seeds.

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ABSTRACT

This study was designed to evaluate the effects of the proprietary science education software, “Conversionoes©,” on students' conceptual and visual understanding of dimensional analysis. The participants in the study were high school general chemistry students enrolled in two public high schools with different demographics (School A and School B) in the Chattanooga, Tennessee, metropolitan area. A mixed methods design was used in the data collection and analysis to provide a holistic view of the impact of the software on student learning, via a value-added design.

The resulting qualitative and quantitative data indicated that the Conversionoes© software enhanced the treatment groups’ conceptual and visual understanding of dimensional analysis. In fact, when all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes© into the general chemistry classroom appeared to have a positive impact on student conceptual and visual understanding of dimensional analysis. This was supported by the quantitative data, which indicated a significant difference between the overall pre-test and post-test scores of the treatment groups ($n = 14$, $t =-2.896$, $p = 0.008$). The treatment groups’ data were comprised of performance test results from Schools A and B.

The descriptive statistics indicated that in general African-American students benefited the most from the software. African-American males had the highest increase in proficiency, 18%; followed by African-American females, 16%; White males, 10.22%; and White Females, 9.67%. With respect to gender, females had the highest increase in proficiency, 15.59%, males increased on average by 12.42%.

More importantly the software elevated student performance in all of the ethnic groups and both genders, helping students make gains in their proficiency levels of dimensional analysis

problem solving. The qualitative data also showed that most students valued their experiences using the Conversionoes© software and claimed that it improved their knowledge of all aspects of dimensional analysis.

CHAPTER 1- INTRODUCTION

Rationale

“'Tis a lesson you should heed, Try, try again. If at first you don't succeed, Try, try again. - Thomas H. Palmer (1782 - 1861) Teacher's Manual (1840)...”

I resigned my position as an explosive engineer for the United States Army on a quest to improve science education after I read a report by the National Assessment of Educational Progress (NAEP, 2005) that stated only 54% of twelfth graders had basic science knowledge and 13% of twelfth grade students were proficient in science. The NAEP defines “basic” science knowledge in association with students who demonstrate some knowledge and certain reasoning abilities required for understanding the Earth, physical, and life sciences at a level appropriate to grade 12, while “proficient” refers to students who capably demonstrate the knowledge and reasoning abilities required for understanding the Earth, physical, and life sciences at a level appropriate to grade 12. Even more alarming, the analogous NAEP basic versus proficient science achievement data for twelfth-grade African-American students was only 19% and 2%, respectively. And I—an African-American chemical engineer—was ignorant of the fact that there were so many students that could never follow in my footsteps due to their reduced proficiency levels. In fact, I was stunned to learn that students could spend twelve years in school, emerge with so little knowledge of the Earth, physical and life sciences, and expect to be intelligent and informed global citizens. I decided at that very moment that I had to do something to increase these proficiency levels. Despite my newfound resolve, I knew going into my journey that trying to convince all students to choose careers in science and technology was unrealistic. My main goal was to help increase science literary because I believe our future depends on helping American students better understand what is happening in the world around them.

After months of pondering these alarming statistics, I felt the best way for me to "do something" was to formally educate myself about the problem, which is what led me to pursue my doctoral studies in science and technology education at Louisiana State University. I began by investigating how it was even possible to go through twelve years in the American public educational system and not be proficient in science. After my first semester, I quickly realized that there was no easy answer to this question. Thus, finding a solution on how to "fix it" would be equally difficult.

It became clear that my new mission statement for life to improve science education in America was too ambitious…that I needed to focus my energies on finding ways that I could improve learning in one content area. Since my undergraduate degree is in chemical engineering, the obvious choice for my research would be identifying ways to enhance teaching and learning in chemistry. But even that topic seemed too broad. Given that I subsequently earned a Master's in Information and have incorporated a minor in education technology in my current doctoral program, I decided to explore the effective integration of educational technology tools in the enhancement of learning in high school chemistry. The process of deciding on the topic of my research actually took about two years. I probably proposed ten different research areas to my advisor before I settled on my final topic. This process was aided by conversations I had with a high school chemistry teacher in Chattanooga, Tennessee, who succinctly identified the concepts her students had the most difficulty understanding. When I looked at her list, dimensional analysis just popped off the page.

Dimensional Analysis is commonly referred to as Unit Conversion or Conversion Factors and is a process of mathematically manipulating one unit of measure to another unit of measure (e.g. converting inches to centimeters). Although I was immediately intrigued by the fact that dimensional analysis made the list, I contacted three other teachers in the Chattanooga metropolitan area to see if this was a common problem they observed in their classrooms as well. I asked the teachers the following questions:

1. How do you normally introduce the concept of dimensional analysis?
2. What have you found your students have the most problem understanding with respect to dimensional analysis?
3. Do you think integrating technology effectively into your teaching would help your students' understanding of dimensional analysis?

Although the responses varied slightly, the three teachers expressed similar concepts and concerns. Teacher 1 stated, "I normally introduce dimensional analysis by introducing the metric system and have students focus on those units because it is a power of ten based unit system that I have found less confusing than 'our' system. The problem I have found is that students have a hard time grasping the concept because they have no concept of size and have no prior knowledge of what a unit means in relation to other units." Teacher 2 said, "I try to introduce the concept of dimensional analysis by having students solve simple conversion problems using things they are familiar with such as finding how many centimeters are in an inch. Many of them can grasp the concept and can then apply it to problems that are more difficult. Those that have difficulty initially tend to struggle throughout the course." Teacher 3 added, "If there is software already out there to help my students PLEASE let me know. My students need all the help they can get solving various problems because many of them think they understand the concept but when tested on it they do not perform as well as they would like. Mainly due to the fact, they do not understand the logic behind dimensional analysis. The only problem I see with using technology in my class is the availability of computers." After pondering the comments from veteran high school chemistry teachers, I felt confident that I had identified a salient issue in science education—and one that I understood well. Beginning in high school, I easily grasped the concepts associated with dimensional analysis, making it easy for me to successfully convert units in high school chemistry and algebra classes, as well as in later college chemistry, physics and all of my chemical engineering courses.

Dimensional analysis is an essential skill for a number of professions, including mathematics, chemistry and chemical engineering, medicine, and many fields of engineering. Thus, if a student becomes frustrated with this one topic, it could easily deter them from pursuing certain careers in science and technology. Once I could see the micro and macro implications of dimensional analysis, I knew that this is where I was going to devote my energies—developing software to enhance learning in this critical area. I also understood that the tools were in place in most American high schools to facilitate this research and implement proposed improvements. As noted by Shive (2004), “As a result of the recent movement of American schools towards achieving national and state education standards and increased Internet connectivity in schools, we appear to be on the cusp of a transformation in the way science is taught and learned in schools” (p. 1066). The World Wide Web opens numerous curricular and instructional opportunities for science education researchers and teachers to create software to enhance student learning.

> An obvious advantage of software is the ability to concurrently present multiple representations to visualize chemical phenomena. The materials can provide logical links between various representations to aid students’ understanding. Students can be given exercises and exploratory activities that require them to convert one form of representation to another, to reflect on the underlying meaning of the representation, and to see how representations function to support the solution of quantitative problems. Web-based learning environments can also foster process skills, facilitate guided problem solving, and model expert problem-solving strategies. Appropriately designed software materials can help students build mental links to strengthen their logical framework of conceptual understanding and to achieve mastery-level understanding of chemical concepts. (Arasasingham, Taagepera, Potter, Martorell, & Lonjers, 2005, p. 1251)

After evaluating my general research question of assessing student conceptual and visual understanding of dimensional analysis, it was clear that I could not produce the answers I needed from a purely qualitative or quantitative study. Quantitative tests are limiting in that they only tell that students cannot compute the final answer; but they fail to show why. The addition of a qualitative exploration helps to identify why students understand or do not understand certain concepts, or where and when students get confused. Moreover, a mixed-methods approach would also be essential in determining if the educational tool I created actually enhanced student conceptual and visual understanding. The study, therefore, adopted a mixed-methods approach in which quantitative and qualitative data was used to provide complementary insights into the beliefs and approaches adopted by the students (Waters & Waters, 2007).

Statement of Purpose

Dimensional analysis is one of the major fundamental concepts high school chemistry students must grasp. It is also a topic that is taught early in the curriculum; if students have a hard time comprehending this concept, it could taint their view of chemistry as a whole. In other words, students who become frustrated with dimensional analysis and do not understand the concept in a timely way can consequently become lost for the remainder of the course. Due to the cumulative nature of chemistry, students who do not have the proper foundation in dimensional analysis will not be able to solve problems presented later in the semester that rely on those skills, such as molarity. Conversely, if students are able to grasp pivotal concepts early and easily, it could increase their confidence in learning subsequent topics.

The three teacher perspectives discussed earlier point to one conclusion…Today's students are having more difficulty making connections to their prior knowledge of concepts such as algebra and its connection to dimensional analysis. The traditional way of teaching this concept was for the teacher to present simple problems on the board that the class would work together, after which students would work similar problems in the book individually. Most students have a hard time with the conceptual and visual understanding of units in general, and struggle even more with the process of converting them. Too many students, for example, have no concept of size, making it difficult for them to determine if a yard is bigger than a centimeter. Traditional methods provide students with a simple conversion chart that just presents units. However, students often struggle with conceptually visualizing the meaning behind the units and only view them as numbers with no value or relevance. It is precisely these students that have a hard time understanding dimensional analysis.

A number of technology-related terms have cropped up to describe 21st Century students, such as “Power Users of Technology,” “New Millennium Learners,” the “Net Generation” or “Digital Native” (Prensky, 2001; Tapscott, 1999), primarily because they engage in media rich settings that use simulated interactive technologies that give instant feedback. Ideally, by presenting the fundamental concept of dimensional analysis via an educational technology tool specifically designed to enhance student conceptual and visual understanding of that content, it should result in improving learning. Specifically, this tool will present traditional dimensional analysis problems, but allow students to “see” what the numbers mean and how the units interact.

Research Questions

The following overarching question drove this research study: Can supplemental use of interactive proprietary software enhance high school chemistry students’ conceptual and visual understanding of dimensional analysis? Additional sub-questions included the following:

1. How is dimensional analysis currently explained in most high school chemistry textbooks, with respect to student’s conceptual and visual understanding?

(a) What supplemental material is typically provided to enhance students' understanding of dimensional analysis?

(b) What effect does this material have on student understanding?

2. What are the textbook-related difficulties high school students have with conceptual understanding of dimensional analysis?
3. How does the supplemental use of a proprietary interactive software program affect students' conceptual and visual understanding of dimensional analysis?
4. What effect does the software program have on students' perceptions of the process of dimensional analysis and their ability to grasp the logic behind it?
5. How does the addition of the software change the students' dimensional analysis problem-solving proficiency?

Research Vee Diagram

To graphically illustrate and summarize the research for this project, a Vee Diagram was constructed (Gowin, 1981). As shown in Figure 1, the research question is located at the top of the Vee and the sub questions are located within the Vee. Theories, principles and concepts that were applied in this study are listed on the left side. The related events that occurred and objects used in the study are listed below the Vee. The value claims and knowledge claims that are listed were obtained from high school chemistry teachers, and are located along with the transformations and records on the right side of the Vee. Figure 2 represents the study's task flow chart, and a lexicon of research terms follows.

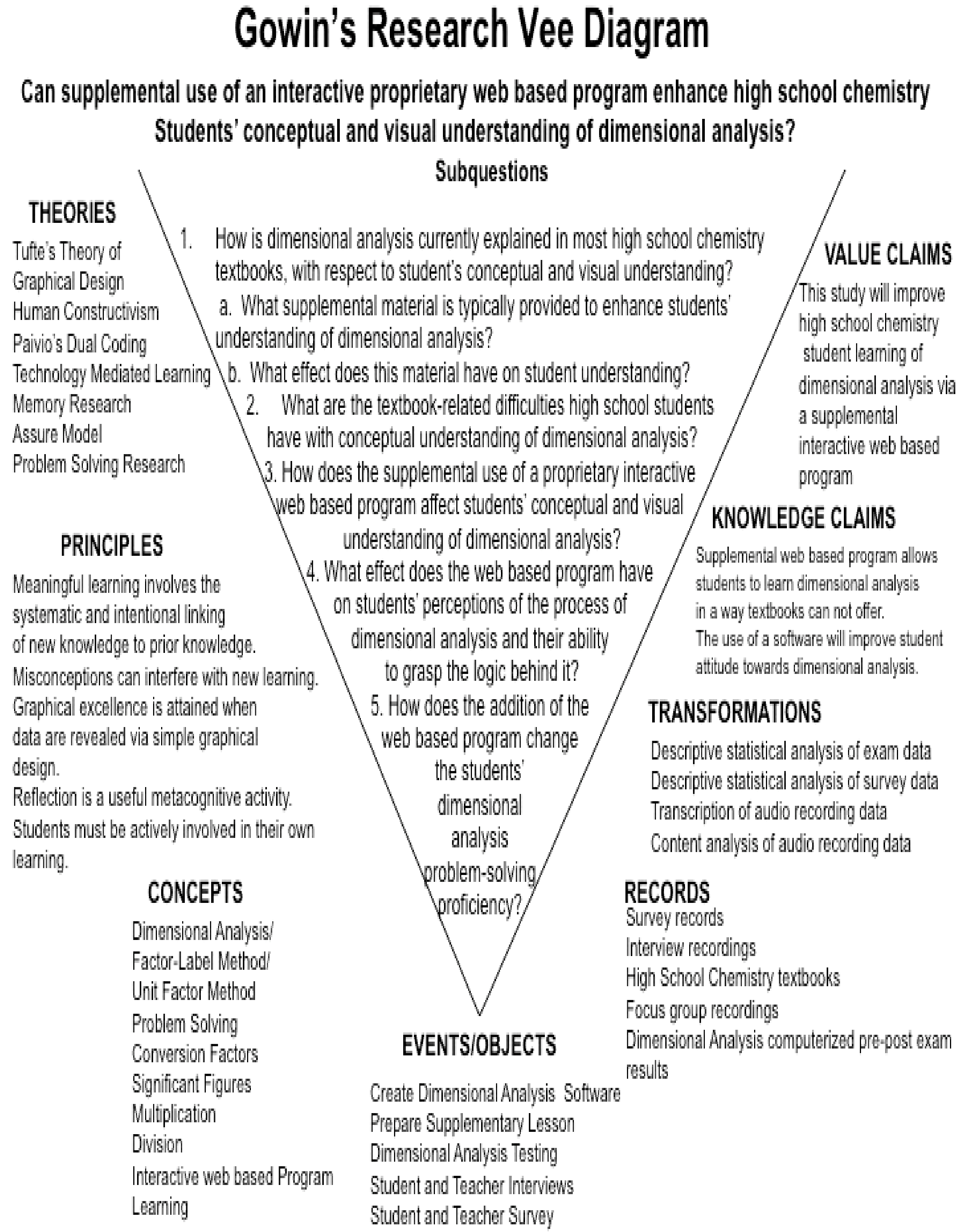


Figure 1. Gowin's Vee Diagram for this research project.

Research Flow Chart

Call to research, general review of dimensional analysis research.

Fall 2007

General Review of Problem Solving Literature in Chemical Education

Fall 2007

Conduct exhausted search of off-the-shelf software as well as web-based programs on Dimensional Analysis

Fall 2007

Literature Review

Fall 2007-Spring 2008

Develop interactive software that focuses on enhancing student Conceptual and visualization understanding of Dimensional Analysis

Spring 2008-Summer 2008

Develop supplemental (35 minute) lesson plans that utilizes Dimensional analysis software

Fall 2008

Identification of study subjects and submission of LSU and Hamilton County Dept of Education IRB forms

Spring 2009

Prospectus Defense

Spring 2009

Prepare Prospectus

Fall 2008-Spring 2009

Make modifications to software

Fall 2008

Test lesson plan with one class to determine efficiency of plan and software

Fall 2008

Make modifications to lesson plan. Make corresponding computerized assessment

Fall 2008

Classroom research

Spring 2009

Data Collection (Textbook, worksheets, pre-post test scores, surveys, and interviews)

Spring 2009

Data Analysis

Spring 2009-Early Summer 2009

Write Dissertation

Spring 2009-Summer 2009

Defend Dissertation

Fall 2009

Figure 2. Research Plan Flow Chart.

Definition of Terms

Conceptual Understanding: The ability to apply knowledge across a variety of instances or circumstances.

Dimensional Analysis (also called Factor-Label Method or the Unit Factor Method): A problem-solving method of manipulating unit measures algebraically to determine the proper units for a quantity.

Human Constructivism: An epistemology which proposes that there is an external and knowable world, and that humans actively construct their knowledge of this world.

Meaningful Learning: The activation of prior knowledge related to any new information, and the association of the new knowledge to relevant prior knowledge.

Problem Solving: The process by which the learner discovers a combination of previously learned rules that can then be applied to achieve a solution for a new problem or situation.

Vee Diagram: A diagram that visually represents the questions, events, methods, and theoretical and conceptual foundation of a research study.

Visual Understanding: The ability to understand graphical representations of subjects or concepts that demonstrate how the concepts relate to each other.

CHAPTER 2-LITERATURE REVIEW

Science Literacy for All Americans

Systematic curriculum reform must understandably begin with identifying the aims of any curriculum and eventually developing effective benchmarks by which successful reform can be measured (McFarlane & DeRijke, 1999; McFarlane, 2001). In the case of science education, this means addressing a number of basic questions: (1) What should a specific science curriculum be designed to do? (2) Who is the target audience for that curriculum? and (3) How should a science curriculum be designed and navigated to enhance its effectiveness? (McFarlane & Sakellariou, 2002). Once these questions are answered and understood, one can begin the process of enhancing an existing curriculum (McFarlane & DeRijke, 1999; McFarlane, 2001).

According to a 2003 report for the National Endowment for Science Technology and the Arts, Futerlab suggested that there are four common rationales for science education:

1. Knowledge of science is practically useful to everyone.
2. We must ensure an adequate supply of scientifically trained individuals to sustain and develop an advanced industrial society.
3. Science and technology are one, if not the greatest, achievement of contemporary society, and that knowledge in this field is an essential prerequisite for the educated individual.
4. Many of the political and moral dilemmas posed by contemporary society are of a scientific nature. (Osborne & Hennessy, 2003, p. 2)

Experts have not always agreed on the nature and purpose of school science (Millar & Osborne, 1998), as well as who should define that purpose—the federal government, an individual state, a school district/system or the school itself. In an attempt to define what the aims of school science on a national level should be, various organizations created standards or benchmarks for science education, which did not always coalesce in any unified way. In fact, “in science education, an initial confusion emerges when defining what is meant by national standards in science education” (Hollweg & Hill, 2003). Historically, setting national goals and developing national standards to meet them are relatively recent strategies in our education reform policy, originating in 1989 as a response to two seminal reports: “Nation at Risk” and “Educating Americans for the 21st Century.” Since that time, high-quality science standards have become central to today’s science education and assessment efforts because they articulate pedagogical goals and help to focus the attention of teachers, students, parents and all others concerned with education on what students should know and be able to do (Wilson & Bertenthal, 2005).

A historical perspective can add to our understanding of contemporary trends and changes in the goals of science education (Shamos, 1995). A great many events, developments and reports have contributed to shaping the goals of the K-12 science curriculum during the 20th Century (Hassard, 2004). During the late 1980s and early 1990s, numerous efforts have been undertaken to lead and influence reform in science education. For example, the American Association for the Advancement of Science established Project 2061—a long-term initiative to improve science literacy—with Science for All Americans (AAAS, 1989) and Benchmarks for Science Literacy (AAAS, 1993) being key early products of this work. The National Science Teachers Association has also been a leader in reform efforts, beginning with its Scope, Sequence, and Coordination project, and more recently by disseminating and supporting the use of the National Science Education Standards. The National Research Council (NRC) brought together these reform efforts by producing a unifying document, the National Science Education Standards, which was intended to guide and support K-12 teachers and administrators in their efforts to improve science programs (Hollweg & Hill, 2003). Although each of these reform efforts are interrelated, this study focuses primarily on the goals and directives of the National Science Education Standards since they generally comprise the ideas of the other organizations.

The National Science Education Standards defines science as a way to "describe, explain and predict natural phenomena and process" (National Research Council, 1996), and it is from this premise that it derives its goals for science education. The goals for school science encompassed in the 1996 NRC report underlie the National Science Education Standards, which are to educate students who are able to:

1. Experience the richness and excitement of knowing about and understanding the natural worlds;
2. Use appropriate scientific processes and principles in making personal decisions;
3. Engage intelligently in public discourse and debate about matters of scientific and technological concern; and
4. Increase their economic productivity through the use of knowledge, understanding, and skills of the scientifically literate person in their careers.

According to the National Academy of Sciences, these goals define a scientifically literate society. The standards for content define what the scientifically literate person should know, understand, and be able to do after 13 years of school science, and should include the following eight categories:

1. Unifying concepts and processes in science
2. Science as inquiry
3. Physical science
4. Life science
5. Earth and space science
6. Science and technology
7. Science in personal and social perspectives
8. History and nature of science (National Research Council, 1996, p. 104)

The National Science Education Standards go beyond defining science and describing a scientifically literate student. They are also designed to encourage policies that will bring coordination, consistency, and coherence to the improvement of science education. The National Academy of Sciences added that the purpose of these goals is to allow all stakeholders to move in the same direction, with the assurance that the risks they take toward improving science education will be supported by policies and practices throughout the system (National Research Council, 1996).

The newest voice of authority on the goals of science education came in the form of the No Child Left Behind Act, a mandate from the U.S. Department of Education, which has added another level of complexity to defining the goals of science education. According to the act, science education should produce a level of science excellence that advances global economic leadership and homeland security in the 21st Century (Office of Educational Technology, 2004). Unfortunately, recent statistics associated with the No Child Left Behind Act are grim: 82% of our nation's twelfth graders performed below the proficient level on the 2000 National Assessment of Educational Progress science test (National Assessment Governing Board, 2005). In order to increase science proficiency levels, No Child Left Behind advocates the adoption of the same format suggested for increasing reading proficiency, namely by using "research" based methods. Despite these well-intentioned recommendations, the reported proficiency levels in reading are also unacceptably low. Thus, effectiveness of this new approach of using "scientifically based research" is still under refinement and much debate, as evidenced in the following statement:

> Federal definitions of such "scientifically based research" studies favor randomized experiments over other study methods. The problem, some education researchers contend, is that while randomized studies can determine whether an intervention works, they cannot answer key questions about why it works, they can't tell whether it works better where it's well implemented, and they can't pick up on any unexpected side effects. (Viadero, 2005, para. 5)

In summary, although the National Science Education Standards, the Benchmarks for Scientific Literary, Science for All Americans, and No Child Left Behind have all emphasized the necessity of science literacy for all American students, none have directly specified what should be required for each branch of science—such as chemistry—to improve science literacy in our schools. However, the central facts, ideas, and skills of chemistry are clearly mapped within all of these standards. For example, the eight defined categories of the National Science Education Standards named earlier do encompass important chemical concepts and expectations, but, again, do not directly refer to specific chemical content, as suggested by Bretz (2008). "…the National Science Education Standards certainly included the concepts important to chemistry because the American Chemical Society's Committee on Education (SOCED) actively participated in constructing the Standards" (Bretz, 2008, p.4).

To help high school teachers better understand the implications of the National Science Education Standards, the American Chemical Society Education Division commissioned the first edition of the Chemistry in the National Education Standards in 1996. Due to new voices in science education, such as No Child Left Behind, a second edition was published in 2008 "to respond to the changing landscape of teaching high school chemistry by providing updated models for meaningful learning" (Bretz, 2008, p.4). The revised document addressed technology integration, English-as-a-Second-Language learners, student misconceptions, and research on learning; it also included web resources teachers could use to help students learn. Importantly, a high school chemistry teacher coauthored each chapter to provide validity to the document and to provide concrete, practical examples that had already been successfully tested in the classroom.

In their article, "Thinking about Standards," Deters and Heikkinen (2008) discussed likely models for meaningful learning in the high school chemistry classroom.

> The ultimate goal of chemistry education reform efforts is not to improve the quality of classroom instruction, develop better textbooks or teaching units, implement better laboratory activities, or use more authentic assessments. Nor is the goal to implement new instructional methods, encourage group work, or even to use "hands on" experiences. While these approaches certainly possess merit, their value is as a means to a common, well-focused end or goal: improved student learning of central facts, ideas, and skills of chemistry. (p. 8)

The authors also recommended shifting the focus from merely looking to standards to define how to best teach science to students; to using the standards as a framework to answer questions concerning what students should know, how they will get there, and how teachers will know when they have attained those learning gains.

Teachers, school administrators, and all stakeholders of science education should focus on the implications of these standards—not only for student learning outcomes, but also in areas such as teacher preparation, curriculum and development, science course offerings and sequencing, technological and laboratory equipment needs, etc. Given the 2009 change in presidential leadership, there may be new initiatives in education that could impact how science education, and chemical education in particular, is defined, implemented, and measured.

Dimensional Analysis

Dimensional analysis, which is also referred to as Unit Conversions, Conversion Factors, Factor-Label Method or the Unit Factor Method, is a problem-solving method of manipulating unit measures algebraically to determine the proper units for a quantity. In general, dimensional analysis involves analyzing the units in a problem and is the most popular approach for solving chemistry problems in high school chemistry (TMW Media Group, 2004a). As such, it is one of the most critical skills beginning chemistry students must master since it enables the student to move from one unit of measure to another. Dimensional analysis is a required skill throughout general chemistry courses; some of the common applications that rely such skills include introductory unit conversions, stoichiometry, and concentration units.

To illustrate the use of this method, we will consider several unit conversions. Some equivalents in the English and metric system are listed in Table 1. Table 1 is an example of a conversion table that could be found in a typical high school chemistry textbook which students use to help solve dimensional analysis problems.

Table 1
Conversion Chart

Mass
1 lb = 16 oz = 453.6 g
1 kg = 1000 g = 2.20462 lb
Volume
1 gal = 3.7854 L
1 cm^3 = 1ml
Length
1 mi = 1760 yd
1 yd = 3 ft
1 mi = 1.609 km

A typical dimensional analysis problem is presented as follows: Consider a field measuring 5.25 kilometers in length. Determine its length in feet. To accomplish this conversion, one must use the equivalence statement:

$$1.609 \text{ kilometer} = 1 \text{ mile}$$

If we divide both sides of this equation by 1.609 mi, we get the following equivalent statement:

$$\frac{1.609 \text{ km}}{1.609 \text{ km}} = 1 = \frac{1 \quad \text{mi}}{1.609 \text{ km}}$$

Note that the expression 1 mi/1.609 km equals 1. This expression is called a conversion factor or a unit factor. A conversion factor is a ratio of the two parts of the statement that relates the two units. To solve dimensional analysis problems one must know the relationship between the two units, in this case kilometers and feet. Using the conversion chart one can determine which factors are applicable for the given relationship and choose them appropriately. Since 1 mi and 1.609 km are exactly equivalent, multiplying any expression by this conversion factor will not change its value. The same can be done for the conversion factors 1 mi/1760 yd and 3 ft/1yd as shown in Table 1.

The field has a length of 5.25 kilometers. Multiplying this length by the appropriate unit factor yields:

$$5.25\ \cancel{\text{km}} \times \frac{1\ \cancel{\text{mi}}}{1.608\ \cancel{\text{km}}} \times \frac{1760\ \cancel{\text{yd}}}{\cancel{\text{mi}}} \times \frac{3\ \text{ft}}{\cancel{\text{yd}}} = 1.72 \times 10^4\ \text{ft}$$

Note that the kilometer, mile, and yard units cancel to leave the unit feet as the final result because the conversion factors chosen cancel the other units used to solve the problem.

Despite the fact that dimensional analysis is a very powerful analytic method, it does feature are some limitations. As noted by McClure (1995), “While most students quickly develop an understanding of the properties of conversion factors, a significant number have difficulty grasping dimensional analysis as a problem solving technique (i.e., linking information given to information sought through conversion factors)” (p. 1093). In other words, with conversion factors, a student does not technically have to understand anything about the problem to get the “right” answer. All she or he needs to do is analyze the units…if the units match up, the final answer will be correct (TMW Media Group, 2004a). Although a student can be “successful” solving a simple dimensional analysis problem by simply matching units, this same logic is insufficient when a student is required to recognize when and where to apply unit conversions. Prior to solving the sample problem, students should be able to understand the proportional implications between kilometers and feet. They should comprehend that since the final answer will be in feet—and they are starting with kilometers—their final answer must be a large number because there are 3,280 feet in 1 kilometer. Conversely, if their answer is smaller than the starting kilometer number, they should immediately recognize they have made a calculation error or applied the wrong conversion factor(s).

“Students like algorithms that enable them to get the answer in one line of calculation by simply stringing together appropriate units” (Canagaratna, 1993, p. 41). While this may be true, students all too often end up applying it in appropriately (Frank, Baker, & Herron, 1987). “Many algorithms are useful shortcuts that will work much of the time (for exercises), but may actually prevent understanding when a student finds a real problem” (Frank, et al., 1987, p. 515). Canagaratna also addressed the pitfalls of using dimensional analysis algorithms without understanding the concepts behind the formulas.

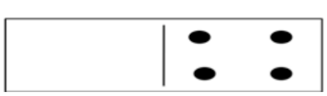
> There are two basic difficulties with the dimensional analysis algorithm; both concern the ambiguities that arise when students rely on using mere units to set up the calculations. Incorrect selections can be made when students do not understand the physical concepts. Principles and concepts are more easily retained if a network of associations can be built to link them. (Canagaratna, 1987, p. 40-41)

McClure (1995) proposed using the game of dominoes to help students link information with respect to dimensional analysis. Games provide an attractive framework for learning activities and students tend to react positively to such approaches (Smaldino, Russel, Heinich, & Molenda, 2005). “Using games in the chemistry classroom can provide engaging and alternative methods of instruction” (Capps, 2008, p. 518). According to McClure’s example, four students (Players 1, 2, 3, and 4) are presented with the traditional domino dilemma most domino strategists face while waiting for their turn to make a play, as follows. Player 1 lays out the first isolated domino.

Isolated domino-Player 1

Figure 3. Isolated domino used to initiate the game.

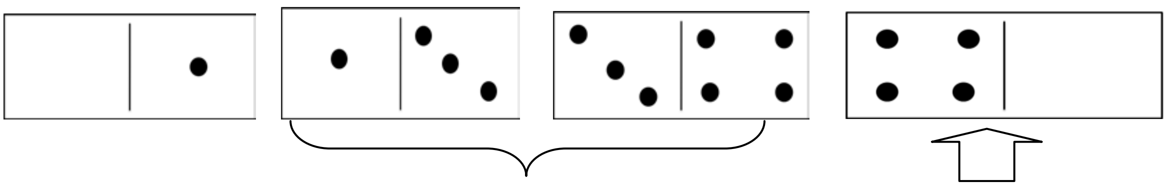
Player 4 has one remaining domino, shown in Figure 4.



Isolated domino-Player 4 (ultimate final result)

Figure 4. Isolated domino needed to be played to win the game.

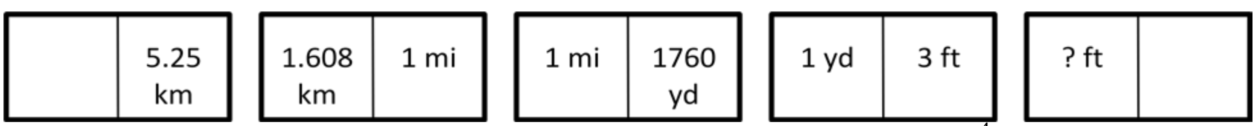
However, Players 2 and 3 still need to play their dominoes. Which dominoes would have to be played that would enable Player 4 to win? In other words, what dominoes would have to be linked together that would produce the results that Player 4 is hoping for? Figure 5 depicts the sequence of plays that would have to occur to enable Player 4 to win. If all players linked their dominoes in the following matter it would facilitate the following final result:



Isolated domino Linking Dominos Isolated domino (final result)

Figure 5. Dominoes used in the game that allowed the final isolated domino to be played to produce the final result.

This strategy of linking dominoes can be applied to unit conversions, using our sample problem as example.



$$5.25\ \cancel{\text{km}} \times \frac{1\ \cancel{\text{mi}}}{1.608\ \cancel{\text{km}}} \times \frac{1760\ \cancel{\text{yd}}}{\cancel{\text{mi}}} \times \frac{3\ \text{ft}}{\cancel{\text{yd}}} = 1.72 \times 10^4\ \text{ft}$$

Figure 6. Dominoes used in a dimensional analysis example.

This analogy between dominoes and conversion factors was developed to help decrease the time required for students to attain a fundamental proficiency in dimensional analysis (McClure, 1995). The initial presentation of a traditional domino problem taps into students' prior knowledge and serves as a platform to extend their knowledge into dimensional analysis. In supplementing dimensional analysis with a linking path, the need for relationships becomes much clearer. Such strategies also provide students with a firmer grasp of relationships and associations, and ultimately enhances their conceptual understanding.

The study described herein expands McClure's domino analogy into the world of educational technology. Specifically, interactive software was created to enhance students' conceptual understanding of dimensional analysis, since "appropriately designed software materials can help students build mental links to strengthen their logical framework of conceptual understanding and to achieve a mastery level understanding of chemical concepts" (Arasasingham, Taagepera, Potter, Martorell, & Lonjers, 2005, p.1251). By allowing students to play with unit conversions in creative ways, we anticipated being able to reduce the tension associated with learning a new concept by encouraging them to make new meaning of old concepts. As Smaldino et al. (2005) have discussed, games provide an attractive framework for learning new activities, but also afford fresh opportunities to practice content, such as math facts, and problem-solving skills. The new software allowed students to practice problems that emphasized the development of dimensional analysis, conceptualization and visualization, analytical reasoning, and proportional reasoning. It also helped them learn to recognize and relate different representations in chemistry.

Technology-Mediated Learning

> As technology spurs scientific advance, it also advances research on instruction and re-defines the goals for the science course…The close coupling of science and technology over the past 25 years has stimulated research that reformulates science instruction, introduces new fields, and explores the impacts of new technologies. (Linn, 2003, p. 727)

A significant body of research exists with respect to the integration of technology and learning. Several researchers have concluded that computer-based environments are effective in facilitating conceptual understanding in student learners, thereby improving mastery of both content and process (Friedler, Nachmias, & Linn, 1990). "Research is also required to determine how best to harness the new technologies to achieve the desired aims" (Skinner & Preece, 2003, p. 205). An information technology learning environment provides students with swift access to new information (Su, 2008), and its reasonable application can make teaching more diversified, flexible, and effective (Dawson, Forster, & Reid, 2006). Effective integration of technology into the classroom has been shown to lead to a number of important outcomes, such as effective learning, improved critical thinking, better problem-solving skills (Hennessey, Ruthven, & Brindley, 2005; Markauskaite, 2007), as well as the developing of other innovative learning tools that can enhance related scientific abilities (McFarlane & Sakellariou, 2002). Technology also fosters interactive, self-directed learning (Goodwin, 1995; Swain, Bridges, & Hresko, 1996; Wellburn, 1996) and higher order thinking skills (Goodwin, 1995; Rogan, 1995; Wellburn, 1996). Technology increases student-centered learning (Goodwin, 1995; Rogan, 1995) and increases student interest in learning (Hollis, 1995; Strommen, 1992).

"The development of technology-based teaching and learning has increased dramatically in the past decade" (Chou, 2005, p. 269). Teachnology-mediated learning (Webster & Hackley, 1997; Alavi & Leidner, 2001; Piccoli, Ahmand, & Ives, 2001) is defined as an environment in which the learner's interactions with learning materials (e.g., readings, assignments, projects, etc.), peers, and/or instructors are mediated through advanced information technology. Shield (2002) defined technology-mediated learning as an "umbrella term which incorporates different approaches to using computers in learning and teaching namely; computer-aided learning, computer-mediated communication, generic computer-based production and presentation tools and computer-supported research tools" (para. 1). According to Shield, computer-aided learning is based on a view of a learner who interacts with pre-test programmed content, typically comprised of multimedia materials used for teaching purposes in a variety of contexts where a degree of repetition is considered desirable. For the purposes of this study, the most applicable technology-mediated learning approach was computer-aided learning.

Computer-aided learning projects are designed to supplement traditional curricula by providing students with an alternative to traditional lectures. Moreover, such projects—such as the software developed for this study—enable students to review the materials as often as they want. The graphics, animations, video clips, and interactive nature of the computer-aided learning project help to actively engage students in the learning process. “Current research on computer-aided learning is very focused on how to represent the learning content and tends to neglect the impact of the user-interface in the learning process” (Schar, Schluep, Schierz, & Kreger, 2000, p. 1). The computer-aided learning project developed for this study focused on how to most effectively represent the learning content, as well as determine the impact of the user-interface, which is addressed in greater detail later in this literature review.

For science educators, a major goal is enhancing student’s understanding of scientific concepts and process skills rather than merely teaching the lower textual-level scientific knowledge (Galilili, 1996). Some promising innovations in science teaching have already been successfully implemented, such as intergrating computer-aided learning environments in order to promote student learning (Bodemer, Ploetzener, Bruchmuller, & Hacker, 2005; Lowe, 2003). The potential benefits of these innovations include enhanced mastery of scientific concepts and improved attitudes toward science (Su, 2008).

Human Constructivism

In Mintzes, Wandersee, and Novak’s “Teaching Science for Understanding: A Human Constructivist View” (2005b), their main premise is based on a definition of human constructivism which asserts that (1) students are meaning-makers, (2) the goal of education is the construction of shared meaning, and (3) shared meanings may be facilitated by the active intervention of well-prepared learners. The authors argued that human constructivism is the most useful framework available to science teachers because it allows students to construct meaning by forming connections between new concepts and those that are part of an existing framework of prior knowledge. They also asserted that human constructivism is the "only comprehensive 'constructivist' epistemology that successfully synthesizes current knowledge derived from a cognitive theory of learning and expansive epistemology together with a set of useful tools for classroom teachers and other knowledge builders" (Mintzes et al., 2005b, p. 46).

As defined by Darmofal, Soderholm, & Brodeur (2002), "conceptual understanding is the ability to apply knowledge across a variety of instances or circumstances" (p. 1). An earlier study (Wiggins & McTighe, 1998) asserted that conceptual understanding can be enhanced when the concept represents a "big idea" having lasting value beyond the classroom, when it resides at the heart of the discipline, when it requires uncovering and refuting misconceptions, and when it offers the potenital to engage students.

Niaz (2005) devised a specific framework to faciliate conceptual understanding, which involves the following six components:

1. A linear relationship should exist between the process of theory development by a scientist and a student's acquisition of knowledge.
2. As a prerequisite for conceptual change, it is essential that students be provided with opposing views that contradict their previous knowledge (alternative conceptions), which forces them to apply critical reasoning/thinking skills.
3. The development of new ideas in science should originate not in objective facts alone, but in a conception, a deliberate construction of the mind – a heuristic principle.
4. The new/alternative framework must initially appear to be plausibe to the students in order to facilitate 'progress transitions' in understanding.
5. The design of interactive 'teaching experiments' should generate situations/experiences in which students are forced to grapple with alternative responses, thereby leading to cognitive conflicts.
6. Task analysis of students' strategies should be based on Pascual-Leaone's Theory of Constructive Operators, which facilitates a conceptual and epistemological origin of students' thinking. (p. 1)

Since dimensional analysis incorporates most, if not all of these criteria, it is a viable candidate for study with respect to conceptual understanding.

Using Analogies to Enhance Understanding

From Mintzes, Wandersee and Novak's "Teaching for Science Understanding: A Human Constructivist View" (2005b), the most applicable teaching strategy for this study can be found in Chapter 7, The Case for Analogies in Teaching Science for Understanding. It involves the use of dominoes as a vital component in helping students link their prior knowledge to a new concept in dimensional analysis. Chemistry courses are full of abstract concepts that can be more easily understood when they are connected to something from daily experiences (Orgill & Bodner, 2004). "Effective analogies can clarify thinking, help students overcome misconceptions and give students ways to visualize abstract concepts" (Orgill & Bodner, 2004, p. 15).

Analogies are tools that can be used to aid in the restructuring of a knowledge framework. Gynn, Britton, Semrud-Cikeman, & Mult (1989) defined an analogy as a correspondence in some respect between concepts, principles, or formulas otherwise dissimilar. More precisicely, it is a mapping between similar features of those concepts, principles, and formulas."In the simplest sense, an analogy is a comparision between two domains of knowledge—one that is familiar and one that is not" (Orgill & Bodner, 2004, p. 15). The familiar domain will be referred to as the anlaog domain, while the domain that needs to be learned will be referred to as the target domain.

For an analogy to be effective it requires the selection of a student world analog to assist in the explanation of the content-specific target (or topic) (Thiele & Treagust, 1992). According to Thiele & Tregust, the analog and target should share attributes that allow for a relationship to be identified. The strength of an analogy, therefore, lies less in the number of features the analog and target domains have in common, but rather in the overlap of relational structures between the two domains (Gentner & Gentner, 1983).

In their review of a number of American chemistry textbooks, Thiele and Treagust (1992) identified various common types of analogies used to convey information, including verbal, pictorial, personal, bridging, and multiple analogies. “Analogies are believed to help in three major ways in that they: (a) provided visualization of abstract concepts, (b) help compare similiarites of students; real world with the new concepts, and (c) have a motivational function” (Thiele & Treagust, 1994, p. 230). In addition to their popular role in communication and learning, analogies are mechanisms for creating and advancing scientific knowledge (Dreistadt, 1968).

The use of analogies has long been credited with playing a strong role in the construction of new knowledge (Dagher, 2005). Nersessian (1992), for example, reported that “analogies are not ‘merely’ guides to thinking, with logical inferencing actually solving the problem, but analogies themselves do the inferential work and generate the problem solution” (p. 20). Well renowned theorists such as Maxwell, Rutherford and Einstein used analogical reasoning as a tool to aid problem solving to explain hypotheses, and to communicate to audiences about early theories of atomic structures (Lewis & Slade, 1981; Shapiro, 1985).

Analogies are particularly effective when the target content is difficult to understand or is foreign to the learner (Duit, 1991). “The presentation of a concrete analogy in this situation facilitates understanding of the abstract concept by pointing to similarities between objects or events in the learners’ world and the phenomenon under discussion” (Thiele & Treagust, 1992, p. 4). In the case of the present study, the “concrete analogy” represents the conversion factors that are in form of dominoes, which are then used to illustrate the linking power of dominoes-conversion factors to known and unknown information.

According to Cosgrove and Osbourne (1985), constructivist learning strategies favor analogies as tools for rendering counter-intuitive ideas more intelligible and plausible, which is why analogies are so important in the field of science. As Dagher (2005) asserted,

> Emphasis on using analogies to enhance conceptual understanding is a serious undertaking in teaching science…As teachers contemplate the role of analogies in furthering student understanding of target science concepts, they might consider using analogies to promote additional educational goals, such as those outlined in the National Science Standards. (p. 208)

Dagher (2005) also reported that "science educators have developed several approaches to instructional analogies to aid students learning" (p. 197). Advocates of using analogies as an instructional strategy view learning as an active process of knowledge construction. Analogies are truly a constructivist learning strategy because they require students to use their prior knowledge to understand the analogy presented to them. Such beliefs support the notion that "knowledge is constructed in the mind of the learner" (Bodner, 1986, p. 873). As students construct knowledge, they seek to give meaning to the information they are learning, and the comparative nature of analogies promotes such meaningful learning. "To learn meaningfully, individuals must choose to relate new knowledge to relevant concepts and propositions they already know" (Ausbel quoted in Bodner, 1986, p. 874). With respect to science pedagogy, science teachers should use analogies when the target concepts cannot be visualized in order to help students paint their own picture with respect to the nature of science. Teachers should also use analogies when they introduce new conceptual material to help students create their own linkages of prior knowledge to new knowledge.

The analogy teaching model that was used in this study is based on the General Model of Analogy Teaching, created by Zeithoun in 1984. This teaching model incorporates nine important steps:

1. Measuring student characteristics related to analogical reasoning ability, ability to handle visual imagery, or task demanding cognitive complexity.
2. Assessing prior knowledge possessed by students to determine whether analogies are helpful or not.
3. Analyzing the learning materials of the topic to determine whether they already contain analogies.
4. Judging the appropriateness of the analogy by considering the extent to which the analogies are (a) familiar and/or (b) highly complex, having many attributes that correspond to the target domain.
5. Determining the characteristics of the analogy in relation to the characteristics of the students.
6. Selecting the strategy of teaching and the medium of preparation.
7. Presenting the analogy in a logical sequence: Introducing the target concept, introducing the analogy (if it is not familiar to students it will need to be explained), connecting the analogy to the target, presenting the analogous attributes one by one starting with the most salient first, using transfer statements to present the irrelevant attributes, and finally discussing those irrelevant attributes.
8. Evaluating the outcomes by determining students' knowledge of attibutes of the topic and identifying misconceptions they might have acquired from using the analogy.
9. Revising the stages after evaluating every stage of the model in order to determine whether additional discussion, an alternative analogy, or a different strategy is needed. (Dagher, 2005, pgs. 197-198)

Although this analogy teaching model is relatively elaborate and requires sequential steps, it was appropriate for this study because of its robustness, which was deemed essential for an undertaking of this magnitude and complexity. To ensure that students were familiar with analogies, the students were first given an introductory lecture and discussion on how analogies can be used to help understand unfamiliar topics, followed by a lesson about conversion factors and how they are similar to dominoes. The students were then asked to create their own dominoes using conversion factors, thus making dominoes the functional analogy.

In summary, the primary role of analogies is to enhance student conceptual understanding in innovative and judicious ways. Therefore, teachers need to use analogies only where appropriate and applicable.

Effectively Assessing Understanding

A principal goal of science education is the development of thinking, reasoning, and problem-solving skills to prepare students to participate in the creation and evaluation of scientific knowledge claims, explanations, models and experimental design (Klahr & Dunbar, 1988; Kuhn, 1993; Metz, 1991; Schnumble, Klopfer, & Raghavan, 1991). But how does one assess if those goals are being met? In the view of human constructivism, assessment is a potentially powerful mechanism for encouraging and rewarding meaning-making (Mintzes, Wandersee & Novak, 2005a). The assessment techniques presented by Mintzes et al. are grounded in two principal assumptions: (a) understanding is not meaningfully revealed by "normalized" comparisons among students, and (b) conceptual change is not adequately represented by a single, "standardizied" alphanumberic score (p. xxi).

Unfortunately, one of the hindrances to true science education reform is the absence of good assessment instruments that can measure the value added to student learning by new ways of teaching or enhancing available materials in innovative ways (Evans, Midkiff, Miller, Morgan, Krause, Martin, Notaros, Rancour, & Wage, 2001).

> Good assessment of science education will determine students' level of subject mastery, how well they understand fundamental scientific concepts and can use them in problem solving or explanatory situations, and whether they are able to think and express themselves in a scientifically valid manner. In short, developing assessments that accurately reveal students' conceptual understanding is critical to attaining the goal of a scientific literate citizenry. (Klymkosky, Gheen, & Garvin-Doxas, 2006, p. 3)

Effective implementation of proper assessment activities in a classroom can help to achieve such goals, and more importantly, provide information about progress toward these goals (Duschl & Gitomer, 1995). As such, effective science educators—who understand that meaningful conceptual undestanding in science goes far beyond knowing facts and labels and only becomes meaningful when it can be used to explain or explore new situations—have begun to develop a range of assessment instruments that focus on conceptual understanding rather than the recall of isolated bits of information (Klymkosky et al., 2006). To assess student's conceptual understanding in this research project, two strategies advocated in "Assessing Science Understanding: A Human Constructivist View" were used: (1) Using Structured Interviews to Assess Science Understanding, and (2) Using Software as an Assessment Tool (Mintzes et al., 2005a).

There is a growing consensus, however, that traditional quantitative assessment tools are largely ineffective for producing an adequate description of what learners know, and how they are able to build upon and revise that knowledge (Southerland, Smith, & Cummins, 2005). To better evaluate a student's conceptual understanding, researchers have turned to more descripitve tools, such as the structured interview, whereby students are asked to explain their understandings in their own words and/or apply that knowledge in selected tasks (Southerland et al., 2005).

> Historically, use of the structured interview as a means of investigating the process of learning began with Jean Piaget's 'method clinque'…Since that time the structured interview has evolved into a way of framing a dialogue between the student and the research in which the student is asked to talk freely about a concept or topic and/or perform some task while thinking aloud. It has become the qualitative method most widely used to explore how students understand natural phenomena. (Smith & Southerland, 2008, Theory and Reseach sec., para. 1)

The structured interview provides an opportunity to interpet a student's explanation of his or her conceptual understanding. Structured interviews can also be used to assess a student's entry level of concept understanding, or identify any misconceptions that students may hold after encountering new material, say, after a classroom lecture. Essentially, the goal of a structured interview is to create an environment where students feel comfortable enough to share their thought processes while they are solving problems, analyzing data, and performing other tasks—all with the goal of enabling the researcher to better understand their conceptual understanding.

When interviews are conducted to provide insights about understanding, it is critical that the researcher make the intent of the interview clear to interviewees so that they can explain as much as possible what they are thinking (White & Gunstone, 1992). “It is crucial for the researcher to emphasize that the interview is not a test to be scored and that their performance will no way affect their course grade” (Southerland et al., 2005, p. 85). Many have found that structured interviews are sufficiently valuable to justify the amount of time and labor they can require because they allow students to express what they know and how they apply that knowledge in their own words. Essentially, they offer insights not typically obtained by other methods (White & Gunstone, 1992; Smith & Southerland, 2008). Such interviews can allow researchers to develop subtle insights of students’ conceptual understanding that have been shown to be very useful in planning and refining instruction (Bishop & Anderson, 1990; Lewis & Linn, 1994).

Effectively structured and implemented interviews can serve as deep probes of a student’s understanding of single or multiple concepts (Southerland et al., 2005). During a structured interview, the researcher uses a set of questions call “probes,” which have been designed in advance of the interview, to assemble a more detailed understanding of the student’s understanding of a specific concept. In a structured interview students are asked to explain their thought processes while solving problems and/or identifying specific scientific phenomenon shown to them in a pictorial or digital format. To be effective the researcher must watch and listen intently to everything the student says and does, asking only those questions that help the researcher better understand the learner’s dialogue and actions.

The most critical decision in planning a structured interview is the selection of tasks to be used during the interveiw process.

> The interview task should be tightly focused on the concept of interest and at a level of difficulty appropriate to the learner. It should be carefully structured to focus only on

> likely conceptual difficulties based on prior experiences with similar students. (Southerland et al., 2005, p. 73)

Tasks should be chosen that are already familiar to the students so they can easily recognize them and can focus on explaining their thought processes versus having to wait for detailed instructions about the task at hand.

The rules of thumb for structuring interview quesitions, which was eludicated by Southerland et al. (2005), were used in this research project:

> 1. Focus questions should require the application of the concept, without forcing an explicit definition.
> 2. Do not force the student into a specific response to a graphic. If the student does not have an understanding of the concept that allows them to make a decision about a specific instance, do not force them to choose.
> 3. Specific definitions of the concept (if needed) should be asked for only after understanding the student's response to the focused questions. This prevents students from early closure on a rote definiton.
> 4. It is important for the interviewer to wait at least three to five seconds after each prompt before trying to interpret the question or ask another. Tobin (1987) showed that students' responses become more elaborative if the wait time technique is applied. (p.76)

In addition to using Southerland et al.'s (2005) guidelines for interviews, the researcher also employed what is known as "sorting interview" guidelines. "In a sorting interview the student is presented with a group of objects to be sorted according to specific instructions that can be structured in many different ways to match the purpose of the assessment" (Southerland et al., 2005, p. 79). For this study, students were asked to determine which of the units was larger or smaller, and/or rank the items by size with respect to their metric unit. This exercise resembled what the students would be experiencing using the proposed software.

> One of the strengths of sorting task is the variety of sources of data they provide. Depending on the exact nature of the task these may include the students' verbal explanations and nonverbal cues, the specific graphics used by the student during the task the grouping of cards produced, and the order in which they are arranged. (Southerland et al., 2005, p. 82)

The last interview assessment tool that was incorporated in this study was Problem Solving and Process Interviews. Problem Solving is a formative assessment used in all chemistry classes where the main emphasis is on the final answer which is either marked “right” or “wrong.” The emphasis is very rarely on the process behind reaching the final answer. The problem-solving interview is designed to focus on the thought processes students used in reaching their final answer. “In an interview setting, a student is asked to attempt to solve a problem while ‘thinking aloud,’ explaining as much as possible about what she is doing, why she is doing it, and what her symbols and actions mean” (Southerland et al., 2005, p. 82). According to Southerland et al., selecting the problems to be used in the problem-solving interview is the most critical part of interview preparation. For this portion of the research, the problems that were chosen were very similar to the problem used in the software; one problem from each of the three levels was presented for the students to solve during the interview.

The final assessment tool used to ascertain student conceptual understanding is based on San Diego State University Professor Katheleen M. Fisher’s work using the SemNet software as an assessment tool.

> SemNet is a Macintosh-based tool that has been employed with 3rd graders studying ecology, middle school children exploring difficult topics like sex and drugs, high school students studying biology, college students learning history, music, literature, and science, and students enrolled in music and physiology college courses being taught across the World Wide Web. (Fisher, 2005, p. 198)

The Semnet-based assessment examines the declarative knowledge structures of students, i.e., students’ knowledge, about a topic (Fisher, 2005). The SemNet assessment is organized as follows:

1. SemNet-based assessment is generative, not responsive.
2. The semantic network that a student produces allows the reviewer to see not only what concepts and relations the student chooses to include in describing a particular topic, but also reveals the student’s higher order structure—that is, the way in which a student’s knowledge is organized.

3. Semantic network construction requires a relatively high level of precision, largely eliminating the ambiguity inherent in text and essay.
4. In creating knowledge representations, students must make the relations they perceive between ideas explicit (whereas those relations are often implicit in essays).
5. An indirect but very important effect of assessment via knowledge representation is that it promotes good thinking and learning habits.
6. Another important consideration in the use of computer-based semantic networks for assessment is that, while they do require qualitative evaluation, review is augmented by powerful automated scoring procedures. (p.203)

A proprietary software was created for this study and some of the strategies noted above were applied where appropriate.

The main reason for using computer-aided learning in science education is to improve a student's ability to organize domain-specific knowledge and to construct robust networks or ideas. Moreover, as stated by Hundson (2004),"Computerised learning clearly offers exciting potential for improving student learning, either as an aid to or as a replacement for traditional formats, or for development of innovative approaches" (p. 887). The challenge for science education researchers, however, is not only to integrate computer-aided learning into the curriculum, but also to evaluate its impact on conceptual understanding of the target content.

When evaluating whether a particular style of computer-aided learning tutorial (such as the one proposed in this study) will result in superior learning (ability to apply and retain knowledge), it is critical to use a valid assessment tool that measures the desired learning outcomes (Hundson, 2004). Well crafted assessment tools that are strategically built into software can help capture this knowledge. The assessments built into the proposed software were based on the principles outlined in this section. Similar to the SemNet software, the proposed software involved three main types of assessments: diagnostic assessment, embedded or formative assessment, and summative assessment. "Diagnotic assessment is extremly valuable, especially early in the learning process. Identification and remediation of specific problems early in the course can help strenghthen the students' cognitive and metacognitive learning skills, leading to more satisfactory and productive learning experiences" (Fisher, 2005, p. 205). With respect to embedded assessments, the most common error observed, according to Fisher, is failure to consistently organize knowledge hierarchically and temporally. "In particular, students often lack the habit of thinking up a 'hierarchy', yet this step facilitates the knitting together of smaller ideas into larger ones and estabilshes pathways for thoughts to cascade down" (Fisher, 2005, p. 206). Finally, summative assessment provides direct assessment of each student's content knowledge and organizational skills. The focus of these assessments will be on the learning of dimensional analysis and shift from the traditional focus of rote recall to meaningful learning.

Problem Solving Methods

"Helping students develop problem solving skills is a frequently cited goal of science educators" (Blosser, 1998, p. 2). However, Blosser was not the first to make that observation. Nearly 90 years ago, John Dewey (1910) promulgated similar opinions. Champagne and Kloper (1977) noted that the first article in the first volume of Dewey's journal (then named General Science Quarterly) asserted that 'the method of science—problem solving through reflective thinking—should be both the method and valued outcome of science instruction in America's schools" (p. 438). In an earlier work of Dewey, he listed "five logically distinct steps" in the "act of thought," namely:

1. A felt difficulty
2. Its location and definition
3. Suggestion of a possible solution
4. Development by reasoning of the bearings of suggestion
5. Further observation and experiment leading to its acceptance or rejection, that is, the conclusion of belief or disbelief. (p. 72)

Solving problems is the heart of the work of a scientist and without the proper cognitive tools (e.g., problem solving abilities), they would not be able to conduct their work.

Defining problem solving with respect to science education has not been an easy task. Many science educators have tried to categorize and describe the process by which solutions are obtained (Helgeson, 1992). Gagne (1977) referred to problem solving in the following way:

> Problem solving may be viewed as a process by which the learner discovers a combination of previously learned rules, which can be applied to achieve a solution for a novel problem situation…Problem solving is not simply a matter of application of previously learned rules, however. It is also a process that yields new learning. (p. 155)

A little later, Shaw (1983) dissected the act of problem solving into four distinct, yet integrated, processes: (1) interpreting data, (2) controlling variables, (3) defining operationally, and (4) formulating hypotheses" (Helgeson, 1992, p. 9).

Hayes (1981) approach to defining problem solving is simpler, but at the same time more comprehensive than either Shaw (1983) or Gagne (1977). As he asserted in the following statement:

> Whenever there is a gap between where you are and where you want to be, and you don't know how to find a way to cross that gap, you have a problem. Solving a problem means finding an appropriate way to cross a gap. (p. 1)

The main difficulty with determining what constitutes problem solving is clearly defining the word "problem." According to Smith (1999):

> A problem is any task that required analysis and reasoning toward a goal (or 'solution'). This analysis and reasoning must be based on an understanding of the domain from which the task is drawn. A problem cannot be solved by recall, recognition, or reproduction…Whether or not a task is defined as a problem is not determined by how difficult or by how perplexing it is for the intended solver. 'Problem solving', therefore, becomes the process by which a system generates an acceptable solution to such a problem. (p. 8)

As complex a task it is to define the term problem solving, the application of it is even more complicated. Problem solving requires high order thinking skills, such as critical thinking, whereby students approach a problem, recognize relationships, and plan a method for solving it (Schrader, 1987). Lin (1982) discovered that few students approach problems logically, but instead search the text for sample problems or equations that appear to be relevant. “Possessing problem solving skills will aid greatly in the understanding of chemistry problems as much as understanding the underlying concepts in chemistry will improve student’s problem solving skills” (Guthtrie, 1991, p. 14). Also on the subject of solving problems in the field of chemistry, Arasasingham et al. (2005) maintained that “Chemistry as a field of science is inherently a representation at the macroscopic, molecular, symbolic, and graphical level. Consequently, learning chemistry requires the ability to integrate these different representations, as well as to visualize, conceptualize, and solve problems” (Arasasingham et al., 2005, p. 251).

In the last decade or so a viewpoint has emerged that chemical problems must be solved from a concept approach rather than from an algorithm approach (Arons, 1990; Cohen et al., 2000; Nurrenbern & Robinson, 1998; Lyle & Robinson, 2001; Oliver-Hoyo, 2003; Gabel, 1999). The current study is buttressed by the belief that students must first understand and appreciate the problem they are trying to solve, rather than simply arriving at the correct answer by a currently accepted ‘plug and chug’ algorithm. For these algorithmic methods to be useful in the context of learning, an understanding of the underlying concepts is mandatory. In fact, algorithms are derived based on a thorough understanding of the problem. However, once an algoithm has been formulated, its application by others does not ensure an understanding of the problem intended to be solved using it.

One such algorithm that has emerged almost universally in contemporary introductory and general chemistry textbooks is the so-called dimensional analysis method (Deters, 2003). Although this method is considered to be a powerful and highly efficient method, it is unsuitable as an initial teaching tool because it can yield the correct answer by perfunctory unit cancellation, rather than understanding why and how the units are being canceled due to scientific principles (Robinson, 2003; Nurrenbern & Robinson, 1998; Lyle & Robinson, 2001; Cook & Cook, 2005). In other words, when students are presented with dimensional analysis problems, they should first attempt to understand the problem and try to visualize what the quantities represent (TMW Media Group, 2004a). Students should really think about what they are doing when they set up a problem. They should try to ignore the numbers and focus on the concepts. Many students have problems because they do not know what the numbers represent (TMW Media Group, 2004b). Once students truly grasp the concept of dimensional analysis, a general chemistry course can begin to make sense because dimensional analysis problems contain all of the logical quantitative ideas that they need to succeed in chemistry. “Virtually all of the problems in chemistry involve the same kind of reasoning, thus, resulting with the entire chemistry course becoming a series of logical expressions” (TMW Media Group, 2004a).

Studies have demonstrated a significant relationship between students’ problem-solving skills and their performance on understanding science subjects (Chandran, Treagust, & Tobin, 1987; Chiappetta & Russell, 1982; Niaz & Lawson, 1985). Sund and Trowbridge (1973) believed that by using problem solving strategies, students would be able to observe carefully, describe problems, predict as a result of previous knowledge, formulate hypothesize, design and investigate approaches, and synthesize their knowledge to make valid conclusions and generalizations. Analogously, the goal of this study was to help students develop these skills so that they could grasp the logic needed to be successful in chemistry.

Paivio's Dual Coding

Research has shown that the way information is represented matters significantly in the learning process, particularly for memory tasks (Clark & Paivio, 1991). Studies have also proved that pictures are superior to words for remembering concrete concepts (Sadoski, Goetz, & Fritz, 1993). The findings of Mayer and Anderson (1992) suggest that Paivio's dual-coding theory has the strongest empirical support in which students' understanding and retention require the construction of new representations, connections, and problem solving for referential connections. Dual coding theory, developed by Paivio in 1971 and revised in 1991, emphasized that information should be represented with due regard to the functional importance of verbal and visual inputs (Butler & Mautz Jr., 1996).

> Dual-coding theory predicts three separate levels of processing within and between the visual and verbal systems: representational, associative, and referential. Representational structures (either visual or verbal) are formed depending on the nature of incoming information (i.e., visual and verbal information from the environment triggers the visual and verbal systems respectively). Associative processing leads to connections constructed within either the visual and verbal systems, whereas referential processing leads to connections made between the visual and verbal systems. Referential processing is particularly important because dual coding theory predicts that learning will be enhanced when information is encoded in both systems (i.e., dually coded). Information that is dually coded has twice the chance to be retrieved and used (Kobayashi, 1986). (Rieber, Tzeng, Tribble, & Chu, 1996, p. 606)

Instruction that promotes dual coding has obvious advantages. The interconnections between verbal and visual inputs allow cuing from one system to the other. This in turn facilitates the computer-aided learning environment for science learning, although the inputs can be activated independently (Su, 2008). The advantage of having more than one kind of memory coding system is that one code can serve as a backup when another code is forgotten. "Multimedia learning occurs when students use information presented in two or more formats—such as visually presented animation and verbally presented narration—to construct knowledge" (Mayer & Sims, 1994, p. 389).

Mayer and Gallini (1990) reported on the potential of visually-based instruction as a medium for promoting students' understanding of scientific material. Mayer (1989) and Mayer & Gallini (1990) found that learning could be enhanced when words and pictures were coordinated in a single frame (Mayer, 1989; Mayer & Gallini, 1990); while Mayer & Anderson, (1991, 1992) confirmed that when animation and sound were concurrently presented, more meaningful learning could occur.

"For meaningful learning that supports problem-solving transfer, the learner must build an internal verbal representation from the presented verbal information, an internal visual representation from the presented visual information, and referential connections between these verbal and visual representations" (Mayer & Sims, 1994, p. 390). For the purposes of this research, a modified version of the Mayers & Sims model was used, which in its original form suggested a three-process account of how visually- and verbally-presented material might be integrated within the learner's working memory during learning. The modified Mayer & Sims dual-coding model of multimedia learning used in this study is shown in Figure 7.

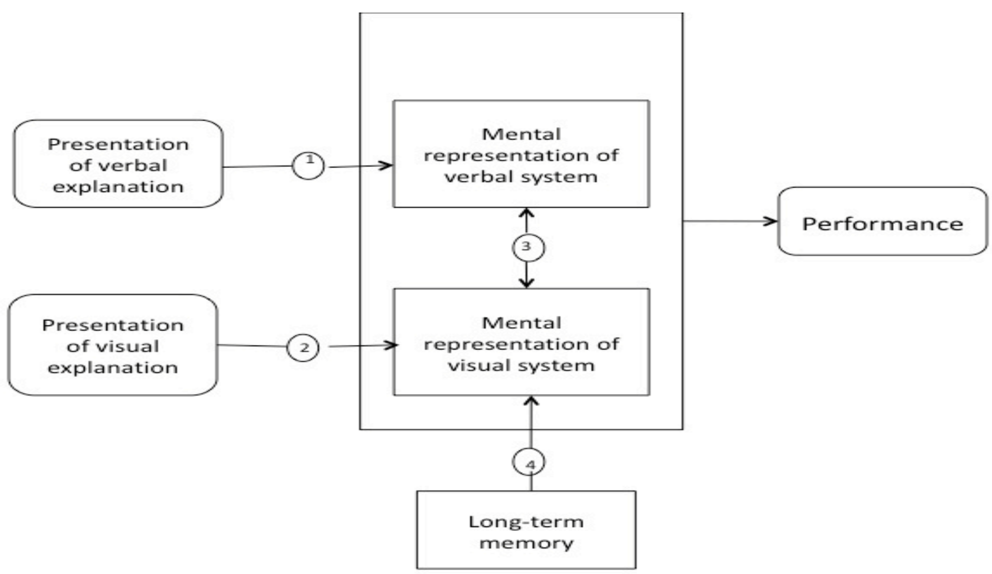


Figure 7. A dual-coding model of multimedia learning. (1) building verbal representational connections; (2) building visual representational connections; (3) building referential connections; (4) retrieval from long-term memory

On the top left portion of the figure, a verbal explanation, such as an oral narration, is presented to the learner. Within working memory the learner constructs a mental representation of the system described in the verbal explanation. The cognitive process of going from an external to an internal representation of the verbal material is called building a verbal representational connection (or verbal encoding) (Mayer & Sims, 1994). On the bottom left portion of the figure, a visual explanation is presented to the learner, such as an animation. Within working memory the learner constructs a mental representation of the visually presented system. The cognitive process of going from an external to an internal representation of visual information is called a visual representational connection (or visual encoding) and is indicated by the second arrow (Mayer & Sims, 1994). “The third arrow denotes the construction of referential connections between the two mental representations, that is, the mapping of structural relations between the two representations of the system...The fourth arrow refers to retrieval from long-term memory” (Mayer & Sims, 1994, p. 390).

Words and pictures are two primary forms of media available in the computer-aided learning environment. Mayers and Anderson (1992) derived a model for the multimedia/computer-aided learning environment from Paivio’s dual coding theory, which they referred to as the contiguity principle. The contiguity principle states that the “effectiveness of mulitmedia instruction increases when words and pictures are represented contiguously (rather than isolated from one another) in time or space” (Mayer & Anderson, 1992, p. 486).

The contiguity principle builds on Paivio’s basic premise that “humans possess two distinct information-processing systems: one that represents information verbally and one that represents information visually” (Mayer & Anderson, 1992, p. 486). According to Mayer and Anderson’s contiguity principle, learning occurs when three basic connections in multimedia situations involving words and pictures are made:

1. Connection 1 involves building representational connections between verbal information that is presented and the learner's verbal representation of that information;
2. Connection 2 involves building representational connections between pictorial information that is presented and the learner's visual representation of that information; and
3. Connection 3 involves building referential connections between corresponding elements in the learner's verbal and visual representation. (pgs. 1-2)

Although Paivio's (1990) dual-coding theory did not emphasize problem-solving transfer as a dependent measure, Mayer & Sims' (1994) modified model of dual-coding theory allows for predictions concerning problem-solving transfer. The findings of Mayer and Anderson's (1992) support a dual-coding model in which a student's understanding and retention require the construction of new representational connections and problem solving for referential connections. Dual coding theory (Paivio, 1971, 1991) emphasizes that information should be presented with proper regard to the functional importance of verbal and visual inputs (Butler & Mautz, Jr., 1996). Theoretical principles from several multimedia studies have helped to explain how information presented as texts and animated sequences interact to encourage learning (Mayer, 1997; Moreno & Mayer, 1999). The proposed study will support the use of a dual-coding theory, which emphasizes that information presenting the functional importance of verbal and visual inputs can enhance student learning (Butler & Mautz, Jr., 1996).

Memory Research

A number of studies in chemical education have addressed the difficulties that students have in learning and understanding chemical concepts and their alternative conceptions in chemistry (e.g., Osborne & Cosgrove, 1983; Nurrenberg & Pickering, 1987; Anderson, 1990). It has been suggested that the psychology involved in forming concepts in chemistry is quite different from other disciplines (Johnstone, 1999, 2000). Johnstone (2000) suggested that we need three levels of thought when assessing concepts within the disciple of chemistry:

1. The macro and tangible: What can be seen, touched, smelled;
2. The sub-micro: Atoms, molecules, ions and structures;
3. The representational: Symbols, formula, equations, mathematical manipulation and graphs. (p. 10)

While the trained chemist can move effortlessly between the three levels, the typical high school student can have great difficulty navigating these areas, and runs the risk of ending up with mental overload.

In recent years, science educators have attempted to take into account various educational psychology models of learning and cognitive structures. One important study by Messick (1994) suggested that individuals have different ways of collecting and organizing information, depending upon their cognitive structures and what they already know. Information processing models examine how we derive information from the environment, as well as how we perceive, organize, store, retrieve and use information. In short, information processing models can provide considerable insights into the way learning takes place (Danilil & Reid, 2004).

It is widely recognized that the acquisition of abstract reasoning skills is important for science education (Niaz, 1987; Kuhn, Amsel, & O'Loughlin, 1988; Linn M. C., 1982). However, researchers in science education have also come to realize that the information-processing abilities of science education students can constrain their learning (Eylon & Linn, 1988). This constraint is thought to apply both to the acquisition of abstract reasoning skills and to the acquisition of knowledge of the chosen domain of study.

> Information is stored in the human mind in the Long-Term Memory, and much of it remains inactive without being affected by the individual’s thoughts (Tulving, 1984). Consequently, it is only possible to have access to this information when it is retrieved to the Working Memory (i.e., a virtual space where mental operations take place) (Shiffrin, 1993). The different types of information stored in the Long-Term Memory can be classified into episodic, semantic, and procedural. (Afonso & Gilbert, 2006, p. 1525)

According to Tulving (1983), the characteristics of the episodic component of long-term memory are an expression of subjective knowledge of personal past experiences. Tulving characterized the semantic portion as expressions of knowledge of the world such as mental model, facts, ideas, and concepts. Tulving also defined the characteristics of the procedural component of long term memory as a demonstration of knowledge used to manipulate objects.

> All the different types of memories can be useful in understanding, as long as accurate mental models are used in simulations (Rapp, 2005); episodic memory or specific situations are structurally similar with the new situation (Ross & Bradshaw, 1994); and body knowledge allows an individual to imagine the sensations of forces on the body and the effects of these forces, for example, on objects (Reiner & Gilbert, 2000). (Afonso & Gilbert, 2006, p. 1524)

The term “working memory,” first discussed by British psychologist Alan Baddeley (Baddeley & Hitch, 1974) in the mid 1970s, has been widely used in the cognitive psychology literature (Baddeley, 1990, 1994, 2000). “Working memory is assumed to be a limited capacity system contain transient information. The function of working memory is less a matter of a storage station to long-term memory than of holding information used for other cognitive work” (Hunt & Ellis, 2004, p. 127). According to psychologists, working memory is a critical part of many important activities needed in science education such as problem solving, reasoning, and comprehension.

The current model of working memory (Baddeley, 1990, 1994, 2000; Della Sala & Logie, 1993) indicates that working memory comprises at least four major components. The first is the central executive that is closely involved in reasoning and problem solving (Baddeley & Hitch, 1974), as well as in the coordination of three specialized subsidiary systems (Baddeley, 1990, 1994, 2000). The three subsystems of this component, which have been extensively investigated, are the phonological loop, visuo-spatial sketchpad, and the episodic buffer, each of which serves as a temporary storage system.

The phonological loop is responsible for storing speech-based material (Baddeley, 2000). The visuo-spatial sketchpad is responsible for storing visual and spacial material. The episodic buffer, the newest member of this trio, is responsible for storing multidimensional representations, i.e., information that is integrated across modalities (Hunt & Ellis, 2004). Baddeley's modified schematic description is shown in Figure 8. (Note that the darker shaded regions represent long-term knowledge.) The episodic buffer is said to provide an interface between the sub-systems of working memory and long-term memory (Tulving, 1972).

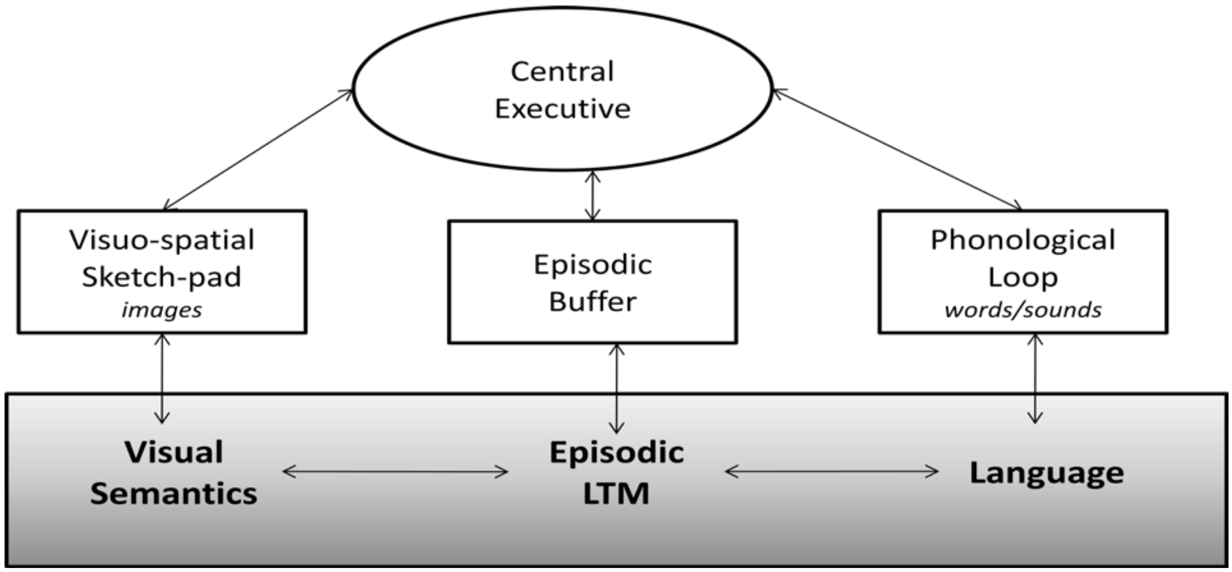


Figure 8. Baddeley's (2000) revised theory of working memory.

One of the strengths of the working memory theory is that it can account for performance on tasks, which involve both processing and storage, and both of these cognitive functions are likely to be required for most forms of scientific problem solving. Johnstone (1984) referred to information being held and worked on. Similar references to both processing and storage were evident in quotes from Opdenacker et al. (1990) and Chandran, Treagust, & Tobin (1987). Information cannot be processed unless it can also be stored on a temporary basis. The Baddeley working memory model also accounts for the fact that human beings can cope with accomplishing more than one task at the same time, depending on the nature of the task as well as on prior knowledge or expertise.

> Another important factor in problem solving, however, is the availability of background knowledge of the domain of the problem, and knowledge of problem-

> solving heuristics or algortihms. It is very clear that expertise in an area can enhance the efficiency with which a limited mental processing and temporary storage resource can function…According to Baddeley (1984) the central executive componet of working memory appears to be closely involved in learning. (Niaz & Logie, 1993, p. 512)

Based on the work of Paivio (1990) and Baddeley (1991), Mayer (2001) developed a memory theory specifically for mulitmedia learning. Specifically, Mayer used Paivio's proposal that information can be encoded using either verbal or visual codes, while from Baddeley he derived the idea of a limited-capacity working memory that can be managed by an executive process.

Mayer's (2001) model presents auditory words so they do not conflict with visual codes that are needed for pictures (Reed, 2006). Reed stated that sounds are organized into a verbal mode and visual images into a pictoral model. In Mayer's model, working memory is used to intergrate the verbal and pictoral mode, as well as prior knowledge stored in long-term memory (Mayer, 2001).

Mayer's research resulted in seven principles for the design of multimedia instruction (Reed, 2006):

> 1. Multimedia principle: students learn better from words and pictures than from words alone.
> 2. Spatial contiguity principle: Students learn better when corresponding words and pictures are presented near, rather than far from each other on the page or screen.
> 3. Temporal contiguity principle: Students learn better when corresponding words and pictures are presented simultaneously rather than successively.
> 4. Coherence principle: Students learn better when extraneous words, pictures, and sounds are excluded.
> 5. Modality principle: Students learn better from animation and narration than from animation and on-screen text.
> 6. Redundancy principle: Students learn better from animation and narration than from animation, narration, and on-screen text.
> 7. Individual differences principle: Design effects are stronger for low-knowledge learners than for high-knowledge learners and for high-spatial learners than for low-spatial learners. (p. 91)

The cognitive architecture of memory theories of Mayer (2001), Baddeley (2000) and Paivio (1991) all show the advantages of using multiple codes. One of the obvious benefits to using multiple codes is in increasing recall (Reed, 2006). A second benefit of multiple codes is that different codes can reduce interference. The third benefit can be found as a result of intergrating multiple sources of information that complement each other, thus allowing the learner to benefit from the sum of their advantages (Ainsworth, 1999). According to Ainsworth, the final advantage of multiple codes with respect to memory is in increasing understanding.

The ASSURE Model

Education has always relied on a variety of "technologies," from pencils and paper to computers. Selecting the appropriate type of technology for instruction requires knowledge of the full variety of available technology and its uses and limitations (Russell, 1994). The implementation process of effectively integrating technology in the classroom involves much more than placing the technology in the classroom and plugging it in. According to Russell, it requires thought as to how the technology fits into the curriculum and how students will receive it.

> It is also important to consider what will be taught (content), who will be taught (learners), how it will be taught (instructional strategies) and technology used, how students will be held accountable for what they are taught (testing to evaluate learning), and how the instructional process will be evaluated (student feedback and teacher analysis). (Russell, 1994, p. 4)

According to Gagne (1985), teaching and learning can be viewed as progressing through several stages, which he referred to as "events of instruction." "Gagne's research revealed that well-designed lessons begin with the arousal of students' interest and then move on to present new material, involve students in practice with feedback, assess their understanding, and go on to follow up activities" (Smaldino et al., 2005, p. 49).

A more recent version of Gagne's events of instruction can be found in the ASSURE model created by Heinich, Molenda & Russel (1993), which incorporates the "events of insturction" but with respect to effective technology integration. The ASSURE model is a procedural guide for planning and conducting instruction that incorporates the use of educational technology, but assumes that training or instruction is required to accompany the recommended educational technology. The ASSURE model is meant for the individual instructor to use when planning classroom use of educational technology (Smaldino et al., 2005).

Because of its applicability to the current study, the ASSURE model was used to effectively create the educational technology tool used for this project. The ASSURE model is intended to provide effective instruction in six steps:

1. A-Analyze Learners: The first step in planning is to identify the learners. You must know your students to select the best medium to meet the objectives. The audience can be analyzed in terms of (a) general characteristics, (b) specific entry competencies, and (c) learning styles.
2. S-State Objectives: State objectives as specifically as possible. They should be stated in terms of what the learner will be able to do as a result of the instruction. The conditions under which the student is going to perform and the degree of acceptable performance should be included.
3. S-Select Methods, Media, and Materials: Build a bridge between audience's present knowledge, skills and attitudes and the objective of instruction by choosing appropriate methods, technology, and media formats, then deciding on materials to implement these choices. There are three options: (a) select available materials, (b) modify existing materials, or (c) design new materials.
4. U-Utilize Media and Materials: Plan how the media, materials, and technology will be used to implement your methods. First, preview the materials and practice the implementation. Next, prepare the class and the necessary equipment and facilities. Then conduct the instruction using utilization techniques.
5. R-Require Learner Participation: To be effective, instruction should require active mental engagement by learners. There should be activities that allow learners to practice the knowledge or skills and to receive feedback on the appropriateness of their efforts before being formally assessed.
6. E-Evaluate and Revise: After instruction, it is necessary to evaluate its impact and effectiveness and to assess student learning. To get the total picture, you must evaluate the entire instructional process. Wherever there are discrepancies between what you intended and what you attained, you will want to revise the plan for the next time. (Smaldino et al., 2005, p. 48)

However, after completing the first two steps of the model, the researcher reached a stumbling block in the Select Methods, Media, and Materials phase. After an exhaustive search it was clear that there was not a commercial-off-the-shelve educational technology tool that would address the first three steps. The third option of designing new materials was the only way to address the learner and the objective adequately. Once the new materials were properly designed, the researcher was able to continue with the remaining steps of the model. A proposed model of the software is available for review in Appendix A.

Tufte's Theory of Graphic Design

> In our visually oriented age, science and technology education rely heavily on the use of pictures to present technical information. Today's students live in an information rich environment with visual images, and educational materials are no exception. Because educational materials must compete for attention in this rich visual environment, all types of teaching resources from traditional textbooks to the latest educational technologies contain a wealth of pictorial representations. In science and technology education these pictures are very diverse, ranging from realistic drawings and photographs to highly abstract diagrams and graphs. The educational emphasis on pictures reflects the widespread use of technical pictures by practicing scientist and technologist across many different fields. (Lowe R. K., 2003, pgs. 1-2)

The introduction of computers, Internet and online-learning gives educators the opportunity to create courseware that is visually captivating (Jacobs, 2005). With increased computer power and greater access to the Internet, researchers have studied ways to tailor visualization opportunities for student use (Linn, 2003). "Visulizations from a part of scientific practice could play an important role in science education" (Linn, 2003, p. 729). Current research programs are investigating the design of innovative technology-enhanced learning environments that help students develop science, language, and technology literacy (Edelson, 1999; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Linn, Davis, & Bell, 2004; Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001).

To effectively create a technology-enhanced learning environment with respect to effective and efficient use of visualization for this study, the principles of Yale Professor Edward R. Tufte were used. Tufte is best known for his four-volume series (detailed below) on information architecture and graphic representations, which revolve around the common theme that images can convey large quantities of information in a compact fashion—but if and only if they are constructed through thoughtful designs that concentrate on efficient and effective ways of presenting information.

Tufte's four-volume series describes his philosophy in the following sequence: The Visual Display of Quantitative Information (1983), Envisioning Information (1990), Visual Explanations (1997), and Beautiful Evidence (2006). This series contains information on architectural design principles for communicating information directly via pictures and for using pictures to support the communication of text. The main principles that will be applied in this study can be best summarized as follows:

1. Enforce Visual Comparisons
2. Show Causality
3. Show Multivariate Data
4. Integrate All Visual Elements
5. Authorship and Documentation
6. Content Driven Design

Enforce Visual Comparisons

Generally, if data is used to answer a particular research question, it should feature a comparative component. In other words, with what is this data to be compared? By applying the enforce visual comparisons principle, designers can ensure that the comparisons they are trying to convey are clear. Tufte (1997) provided several suggestions on how one should apply this principle. One example found in Visual Explanations, Tufte labels “insistently, enforce appropriate comparisons.” To support this recommendation, Tufte described in great detail the failures of the Challenger space shuttle. One of the major problems he discovered was that engineers had trouble clearly expressing their reservations in explaining their data. In addition, they did not compare the right properties to lead towards causality, to justify the cancellation of the mission. The Challenger is a prime example of the importance of properly addressing the comparison question, as depicted in the figure below.

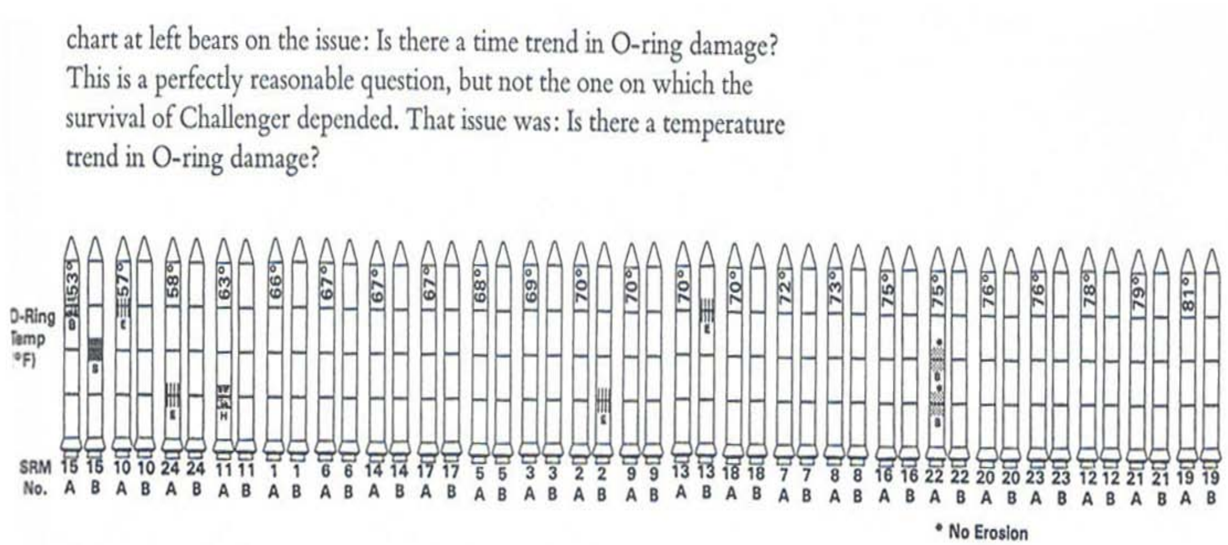
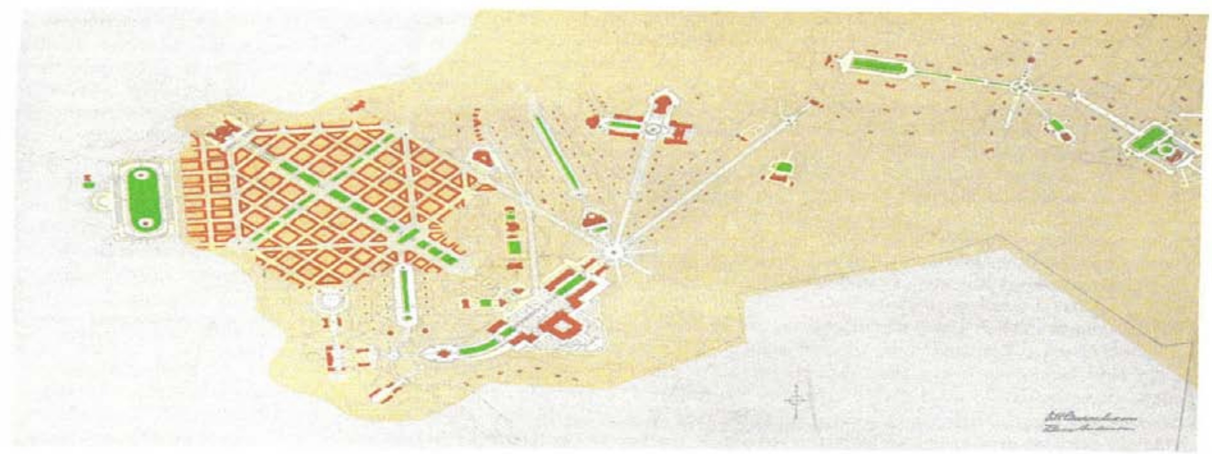


Figure 9[1]. Tufte’s example of the importance of properly addressing the comparison question.

Envisioning Information

(Tufte, 1990) also included a suggestion on how to implement/emphasize visual comparisons using thickness, color, and/or weight. In fact, Tufte used an entire chapter in this volume on color and information, in which he quoted Imhof’s first rule of color contrast—that color spotted against a light gray or muted field can highlight and italicize data, as well as help to weave an overall harmony (Tufte, 1990). In presenting data using this rule, the audience can clearly see where to focus their attention due to the effective use of color, as seen in Figure 10.

[1] Permission has been granted for the use of this image.



Daniel H. Burnham, "Plan for a Summer Capital of the Philippine Islands, at Baguio," in Daniel H. Burnham and Edward H. Bennett, edited by Charles Moore, *Plan of Chicago* (Chicago, 1909), p. 28.

Figure 10[2]. Tufte's example of effective use of color.

Tufte (1997) also suggested that whenever possible, one should show comparisons adjacent in space rather than over time. Tufte's strategy for understanding narrative graphics maintain the underlying information and enable one to discern how the design changes with respect to time. This will make it easier for the viewer to see the changes without distractions. Tufte also recommended using the smallest effect difference, which avoids creating a greater visual distinction than the data actually implies. As Tufte advised in Visual Explanations, "Make all visual distinction as subtle as possible, but still clear and effective" (p. 73).

Show Causality, Mechanism, Structure, and Exploration

The principle of showing causality, mechanism, structure and exploration is closely related to the previous principle, and was also used in the Challenger example. However, Tufte (2006) best illustrated this principle with one powerful graphical image: Charles Joseph Minard's rendition of the terrible fate of Napoleon's army during the 1812-1813 Russian campaign (Figure 11). From this one image it can easily be deduced how and where Napoleon's army was defeated. "Minard depicted a possible causal variable by means of a graph of temperature during

[2] Permission has been granted for the use of this image.

the retreat-for Napoleon was defected not only by the Russian Army but also by the General Winter" (Tufte, 2006, p. 129).

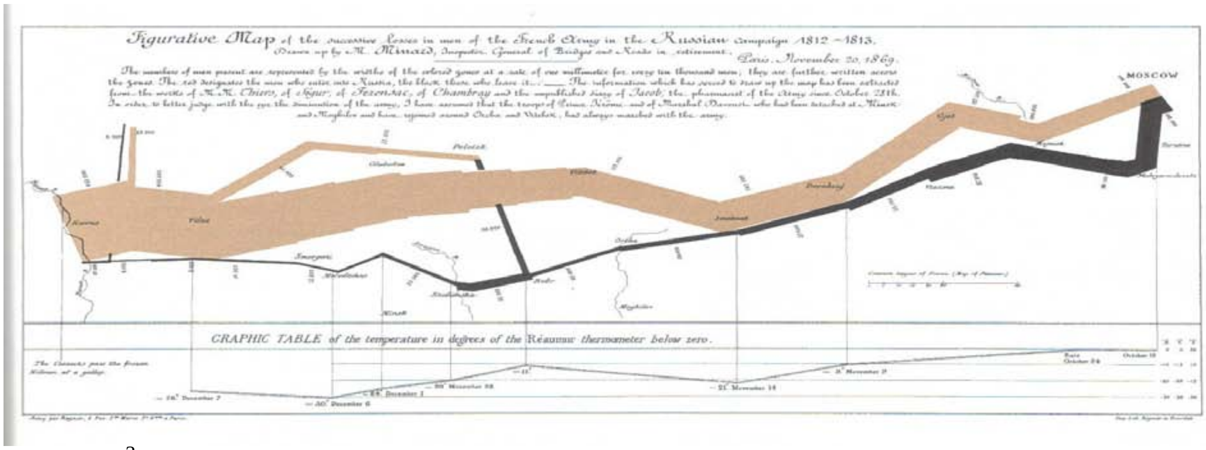


Figure 11[3]. Tufte's example of showing causality.

<u>Show Multivariate Data</u>

Tufte (1990) also suggested showing data on more than one dimension, thereby enhancing the meaning and point of the graph. In Envisioning Information, Tufte stated that multivariate representation is the best design solution for a wider range of problems in data presentation. It allows viewers to make comparisons at a glance, i.e., through uninterrupted visual reasoning. As shown in Figure 12, which depicts various drawings of early 20th Century trains, the viewer can easily spot the data differences among the six trains.

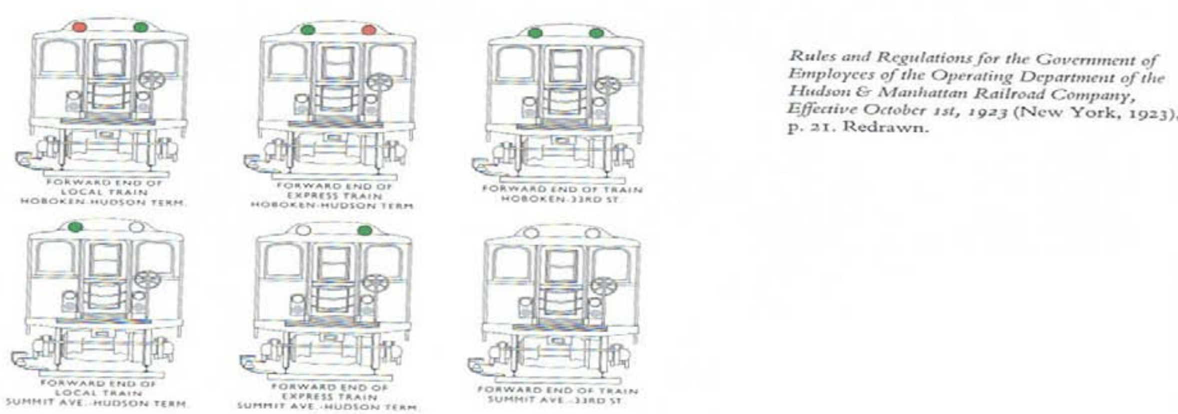


Figure 12[4]. Tufte's example of showing multivariate data.

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[3] Permission has been granted for use of this image.
[4] Permission has been granted for the use of this image.

Integrate all Visual Elements

Tufte (1983) also suggested that when integrating all visual elements in a graphical representation, one should try to include images, text and numbers where visually appropriate, instead of pushing all contextual information to the appendix. In addition, Tufte introduced the concept of data/text integration in The Visual Display of Quantitative Information. He stated that data graphics are paragraphs about data and should be treated as such. He went on to say that words, graphics, and tables are different mechanisms with a single purpose—the presentation of information (Tufte, 1983). As such, they should be presented as one cohesive unit not as separate entities.

Authorships and Documentation

In Beautiful Evidence, Tufte (2006) delineated the steps needed for good documentation, namely, describe the evidence; provide a detailed title, indicate the authors and sponsors, document the data sources, show complete measurement scales, and point out relevant issues (Tufte, 2006). In his earlier work, Visual Explanations, Tufte (1997) used 15 pages to analyze the Challenger disaster to show the catastrophic results of not abiding by this principle, but also noted that the title slide did not include the names of the authors. This implied that no one wanted to take ownership of the information being presented. Tufte (1997) asserted, “Authorship indicates responsibility, both to the immediate audience and for the long-term record” (p. 40). Without any indication of accountability, a document “might well provoke some doubts about the evidence to come” (Tufte, 1997, p. 40).

Content Driven Design

In Visual Explanations, Tufte (1997) stressed above all to show the data, and pay closer attention to the substance of the data—nothing else. In his subsequent publication, Beautiful

Evidence, Tufte (2006) stated that analytical presentations ultimately depend on the quality, relevance, and integrity of their content. He used this principle to stress that architectural and graphic representations should be content-driven craft and should, as a priority, address the following question: What are the content reasoning tasks this display is supposed to help with? Once this question has been comprehensively addressed, then one can apply the other five principles to create a graphic that adheres to Tufte's theory.

Tufte Tools

In addition to Tufte's main principle described throughout his four-volume series, he also developed a variety of tools that can be used to create or assess graphics. They include lie factor, data-ink ration, data density, and chartjunk.

Tufte discussed the danger of using ineffective graphs or using graphs to lie within each book of his series. Those who do so tend to use area of volume instead of linear scales to exaggerate differences and amplify or change the scale in mid-graph. To gauge the effectiveness of a graph, Tufte provided the "lie-factor" (visual % / actual %), which helps determine if there are exaggerated differences or similarities. The ideal lie factor should be 1.

The next tool Tufte (1983) discussed was data-ink ratio, which is "data" ink/total ink (Tufte, 1983). One can increase data-ink ratio by avoiding heavy grids, using whitespace to indicate gridlines, erase non-data ink (ink that is not providing value) and removing drop shadows, boxes, pointers, redundant legends, and other extraneous objects.

Data density, the next tool developed by Tufte (1990), represents the number of data points divided by the area of the image. To increase the data-density ratio one should increase data-ink ratio, include more data points (use small multiples) and include more variables. Good quality graphics should be comparative, multivariate, high density, able to reveal interactions and comparisons, and include a significant percentage of actual data ink. A practical example of a data-rich plot is a graphical train's schedule that shows start and stop times, locations, directions, routes, transfers, and speeds all on one sheet of paper.

Chartjunk is a decorative element that provides no data and causes confusion. Tufte is clearly "anti-chartjunk" and urges designers to ask the following questions: Is this graphic a distraction? Does this add value to the data? Will viewers focus more on my images and not on the data? Examples of chartjunk include heavy or dark grid lines, ornamented chart axes and display frames, pictures or icons within data graphs, and ornamental shading. As an indication of his aversion to chartjunk, Tufte stated the following:

> The interior decoration of graphics generates a lot of ink that does not tell the viewer anything new. The purpose of decoration varies–to make the graphic appear more scientific and precise, to enliven the display, to give the designer an opportunity to exercise artistic skills. Regardless of its cause, it is all non-data-ink or redundant data-ink, and it is often chartjunk. (Tufte, 1983, p. 107)

Tufte (1983) discussed the rule of 1+1=3 (or more): 2 elements in close proximity cause a visible interaction. Such interactions can be very fatiguing and can show information that is not really there, thereby creating chartjunk. Techniques to avoid chartjunk include replacing crosshatching with solids (preferably pastels) or gray, using direct labeling as opposed to legends, and avoiding heavy data containers.

Although this section only highlights a few of Tufte's main principles and supporting tools, his volumes are rich with information for those who create or use graphical images. The key strength of his work is that Tufte "practices what he preaches" throughout his volumes. He unequivocally explains his principles in text and provides supporting images to further bolster his arguments. His choice of imagery included in these volumes further substantiates the importance of effective information architecture in that one can clearly discern the difference between an effective and an ineffective graphic. The principles described in this section were applied in the design of the educational technology tool made for this project to ensure that the material presented would enhance students' visual and conceptual understanding and not distract from their learning.

CHAPTER 3-METHODOLOGY

Quantitative, Qualitative and Mixed Methods

Experts have not always agreed on the most effective way for conducting research within the field of science education (Wandersee & Demastes, 1992), mainly due to the traditions of its target audience, scientists, and educators. Wandersee and Demastes also pointed out that many science education researchers fail to understand that some questions are better answered by qualitative methods, while others benefit from a quantitative approach; therefore, research should not necessarily be limited to one method. Tashakkori and Teddlie (1998), Patton (1990), and Howe and Eisenhart (1990) all agreed that researchers should first ask one fundamental question: Which methodology best fits the research question being posed?

Since science education research is a cross-section between understanding the science behind the phenomena and understanding the learning process of that phenomenon, it is imperative that researchers take both methods into account. Qualitative research is the analysis and/or description of a phenomenon based on non-quantifiable information such as words (e.g., from interviews), pictures, or objects (e.g., artifacts). Qualitative research addresses how students learn by using explanatory and exploratory techniques. It also generally results in generalizations that can be widely applied. Conversely, quantitative research provides a description or an analysis of a phenomenon that requires specific measurements of variables, e.g., the analysis of numerical data.

To fully assess the process by which students come to understand scientific phenomena, it is imperative that complementary methods be utilized. In other words, a complementary mixed methods approach is required. Mixed methods research is a procedure for collecting and analyzing both quantitative and qualitative data in a single study or in a series of studies, based on priority and sequence of information (Tashakkori & Teddlie, 1998; Creswell, 2003; Creswell, Plano Clark, Guttman, & Hanson, 2003; Green, Caracelli, & Graham, 1989).

Utilizing a Mixed Method

Tashakkori and Teddlie (1998) defined "mixed model" studies as studies that "combine the qualitative and quantitative approaches within different phases of the research process" (p. 19). The main goal of this study was to assess the development of high school chemistry students' conceptual and visual understanding of dimensional analysis via supplemental use of an interactive software program. The research was driven by four main themes that target student conceptual understanding (e.g., Human Constructivism, Dimensional Analysis Problem Solving) and visual understanding (e.g., Tufte's Theory of Graphic Design, Paivio's Dual Coding). Given the complexities of the research questions being posed in this study, a mixed methods design was expected to yield the best results (Tashakkori & Teddlie, 2003) since it utilizes both qualitative and quantitative methodologies throughout the full course of data collection and analysis. The use of mixed methods during each phase of the proposed study helped in achieving well-rounded data collection, ready for triangulation and analysis (Tashakkori & Teddlie, 1998). (See Figure 1, Research Plan Flow Chart.)

The focus of the study was exploratory. To assess the effectiveness of using supplemental software, two groups were used. Therefore, a comparative concurrent mixed triangulated, multiple case study design (Tashakkori & Teddlie, 1998) was determined to be most applicable, since according to Marshall & Rossman (1995), a case study approach is best for answering a question that is exploratory in nature, as well as for determining themes and patterns in the meaning structures of participants. Moreover, Yin (2003) asserted that multiple case designs produce evidence that is more compelling and robust than individual case studies. The two groups consisted of (1) students who only received textbook-based instruction (control group), and (2) students who received textbook-based instruction with supplemental use of the proprietary software (treatment group). It should be noted that both the general chemistry classes were preassembled by high school guidance counselors and administrators prior to this study and could not be manipulated.

Research Site

School A, the primary research site, was a medium size, suburban, grade 9-12 public high school located in the Chattanooga, Tennessee, metropolitan area. At the time the study was undertaken, the enrollment was approximately 1000 students: 60.4% White, 35.5% African-American, 2.7% Hispanic and 1.5% Asian/Pacific Islander/Native American. The total percentage of students classified as economically disadvantaged was 39.4%. The general chemistry classroom demographics reflected that of the school—approximately 65% White and 35% African-American students.

The primary research site was selected primarily because of convenience, since it was one of the schools at which the researcher volunteered as a mentor to a youth group. This prior relationship enhanced the administration and the data collection of the study, since the researcher had developed a rapport with the students, teachers and administrators at the school over the course of two years.

School B, the comparison school, had different demographics. Although it was also located in the greater Chattanooga metropolitan area, it was a brand new district school that mainly served affluent neighborhood children. The enrollment at this school was approximately 325 high school students (9-11 grades)—94.9% White, 2% African-American, 1.1 % Hispanic, and 2.0 % Asian/Pacific Islander/Native American. The total percentage of students classified as economically disadvantaged was 13.8%. The general chemistry classroom demographic was 100% White.

The comparison school was also identified because of convenience. At the time of the study, the researcher was doing her student teaching in the field of career and technology education at this school. This relationship enhanced the implementation of this study, since the researcher had also developed a rapport with the students, teachers and administrators at this school and had been encouraged by all to conduct her research at this location.

Research Participants

At School A, the study was conducted with high school students enrolled in a standard general chemistry class. The teacher of the selected chemistry class was a 20-year veteran, white, female, teacher with a bachelor's degree in chemistry from the University of Tennessee at Chattanooga, and a Master's degree in Educational Administration from Austin Peay State University and will also be referred to as Teacher A. Teacher A taught one general chemistry class and one honors/AP chemistry course in the spring semester. The teacher taught the dimensional analysis unit with occasional assistance from the researcher with respect to incorporating analogies into the unit discussions.

The general chemistry class at School A was a part of each student's four-block schedule of classes, with each class block lasting approximately 90 minutes. In addition to the 90-minute daily class time, the students had an extended period of 45 minutes once a week for remediation, review and/or makeup work. Teacher A allowed her students to use the proposed software during that extended 45-minute period.

To avoid skewing the data, the general chemistry class was split into two equally distributed groups with respect to gender, race, socioeconomic status, and academic ability and standing. The general chemistry class had sixteen students total (eight students in the control group and eight students in the treatment group) and six of those students also participated in the interview portion of this study. The control group contained three White females, two White males, two African-American males, and one African-American female. The treatment group contained three White females, three White males, two African-American females, and one African-American male. The researcher relied on the expertise of Teacher A to help with structuring the groups to ensure the group's compositions reflected the overall class with respect to gender, race, socioeconomic status, and academic ability and standing.

At School B, the study was conducted with high school students enrolled in a standard general chemistry class. The teacher of the selected chemistry class was a 20-year veteran, white, female, teacher with a bachelor's degree in chemistry from the University of Tennessee at Chattanooga and a Master's degree in Environmental Science from the University of Tennessee at Chattanooga and will also be referred as Teacher B. Teacher B taught the dimensional analysis unit with occasional assistance from the researcher with respect to incorporating analogies into the unit discussions. Similar to School A, the chemistry class at School B was a part of each student's four-block schedule of classes, with each class block lasting approximately 80 minutes. However, unlike School A, Teacher B allowed her students to use the software for 45 minutes during a regular class period since their schedule did not provide any additional time.

Teacher B taught two general chemistry classes and one honors/AP chemistry course in the spring semester. To avoid skewing the data, her general chemistry class was split into two equally distributed groups with respect to gender, race, socioeconomic status, and academic ability and standing. The general chemistry class had twelve students total (six students in the control group and six students in the treatment group) and six of those students also participated in the interview portion of this student. The control and treatment groups contained three White males and three White females. The researcher relied on the expertise of the teacher to help with structuring the groups to ensure the group's compositions reflected the overall class with respect to gender, race, socioeconomic status, and academic ability and standing.

The primary instructional methods used in both schools were lecture and the completion of worksheets and textbook problems, using the textbook as a reference. At their chemistry coursework level, the students' principal use of dimensional analysis was to solve various dimensional analysis problems and then use those same concepts in future lessons in stoichiometry and molar equations. Prior to the research, Teachers A and B covered dimensional analysis during class lecture and the students had ample opportunities to apply the problem solving skills prior to the supplemental activity was introduced to the class.

Instructional Tools

Software

The software that was designed for this research project, which is described in Appendix A, was based on the ASSURE model as a guide for effective and efficient integration into the traditional high school chemistry classroom. All of the graphical representations were created with respect to Tufte's principles. The name of the software's is "Conversionoes" (which is a play on words between "conversion" and "dominoes"). Conversionoes is a web-based application that was easily accessible to all participants at both Schools A and B.

Conversionoes consists of three main elements: Conversionoes Game, Smaller or Larger, and Dimensional Analysis. The Conversionoes game is based on the traditional game of dominoes, but uses conversion factors as the domino pieces instead of the traditional numbering. The purpose of the Conversionoes game is to expose students to units of measurement with respect to a specific category of the International System of Units (SI) (e.g., length and mass) and to show the linking aspect of units. The Smaller or Larger element of the software was designed primarily to help student's visual understanding of units, although it did require them to use their conceptual understanding as well. In terms of how Smaller or Larger is played, the students are given two units of measurement, after which they have to determine which element is larger or smaller. Once a student enters a decision, he or she sees how the units are represented in household items and which of those items/units is larger or smaller.

The final element of the software allows students to use Conversionoes to help them solve dimensional analysis problems. There are three levels of problems, ranging from Level One featuring more simplistic problems, to Level Three with multiple-step dimensional analysis problems. Students are allowed to click on a “Hint” button to see video tutorials that will help them (1) put their final answer in significant figures, (2) put their final answer in scientific notation, (3) learn how to use a scientific or graphical calculator to calculate their final answer, and (4) provide strategies on how to solve dimensional analysis problems. As students successfully complete a level with at least 90% accuracy, they are able to print a level-specific certification document for their records (e.g., Dimensional Analysis Level One Certified) (see Appendix A).

Textbook

The textbook adopted by Hamilton County Department of Education for high school general chemistry is World of Chemistry by S. S. Zumdahl, S. L. Zumdahl, and DeCoste. The book, which is intended to provide general chemistry knowledge to high school students, focuses on major concepts in chemistry while also highlighting the impact of chemistry on science, technology and society.

The dimensional analysis unit is included in Chapter 5 Measurement and Calculations. Chapter 5 starts by introducing the concept of measurement and its importance, what measurement consists of (numbers and units), the characteristics of measurement and the calculations that involve measurements. The following specific topics are addressed in Chapter 5: Scientific Notation, Units, Measurements of Length, Volume and Mass, Uncertainty in Measurement, Significant Figures, Problem Solving and Dimensional Analysis, Temperature

Conversions, An Approach to Problem Solving, and Density. Although the main focus of this research was on problem solving and dimensional analysis, other supporting elements provided in this chapter were also analyzed to help determine how the textbook authors provided students with the proper skills to be able to successfully understand and complete various dimensional analysis problems.

The topics that were most applicable to this project include scientific notation, units, measurements of length, volume, and mass, significant figures and problem solving and dimensional analysis. According to the textbook, the objective of scientific notation is “to show how very large or very small numbers can be expressed as the product of a number between 1 and 10 and a power of 10” (Zumdahl et al., 2002, p. 110). In this section, the authors stress the importance of measurements and how they always consist of a number and a unit. The objective of the section on units is “to learn the English, metric, and SI systems of measurements” (Zumdahl et al., 2002, p. 116). Here the authors introduce students to some of the fundamental units in the International System, or SI units, and to the commonly used prefixes in the metric system. The objective of the significant figures sections is “to learn to determine the number of significant figures in a calculated result” (Zumdahl et al., 2002, p. 124). According to the authors, the objective of problem solving and dimensional analysis is “to learn how dimensional analysis can be used to solve various types of problems” (Zumdahl et al., 2002, p. 130).

Protection of Human Subjects and Participant Consent

An application for exemption from the oversight of the Louisiana State University Institutional Review Board (IRB) was approved by the board (Appendix H). This study met the qualifications for exemption on the following grounds: (a) the research would be conducted in an educational setting with the approval of the Hamilton County Department of Education superintendent, school principals, and classroom teachers, (b) the study would involve educational and assessment practices, (c) the consent of parents/guardians and students would be obtained prior to beginning the study, and (d) the research participants, district, school, and students would remain anonymous when reporting the findings by assigning pseudonyms and unique user identifications when they submit any results from the web-based software. The consent forms and questionnaire are shown in the appendixes: Appendix H includes a copy of the approval, and Appendix G contains a copy of the investigator's Human Subject Research Course Completion Certificate.

Student and parent/guardian consent forms were submitted and collected prior to the start of the research project. The consent forms for the student and parent/guardian detailed the following information: (a) the purpose for the study, (b) the potential benefits for being included in the study, (c) the potential risk associated with being in the study, (d) the opportunity for the student to opt out of the study, and (e) the assurance of confidentiality of study participants. The Student Consent Form is included (Appendix E), as is the Parent/Guardian Consent Form (Appendix F). All participants (teachers and students) were assured that any information provided (e.g. digitally recorded interviews, test results, documents, etc.) would be secured by the researcher upon completion of this study.

Teacher participants also submitted consent forms prior to beginning the research, as shown in Appendix F. The consent form for teachers explained: (a) the purpose of the study, (b) the potential benefits for being included in the study, (c) the potential risk associated with being in the study, (d) the opportunity for them or their students to opt out of the study, and (e) the assurance of confidentiality of study participants.

Mixed Method Data Collection Procedures

The study required a variety of data collection methods to assess changes in students' conceptual and visual understanding. The data collected was quantitative as well as qualitative in the form of documents (e.g., textbooks and worksheets), interview transcripts, and observation field notes, as well as quantitative, which included survey results and pre-test and post-test results. Appendix B represents a summary of the data collecting techniques and variables associated with each question. In order to address the main research question—would use of a supplemental interactive proprietary software program enhance high school chemistry students' conceptual and visual understanding of dimensional analysis—the researcher used a mixed methods approach to identify the variables and data collection techniques needed to accept or reject the research hypothesis. Although variables are not typically identified in qualitative research, they were identified in this study due to the use of the mixed-methods approach, which also includes quantitative data. The primary independent variable was the integration of the proprietary software on the treatment group. The dependent variable was the learning gains of the students. The data collection procedures are summarized in Table 5 found in Appendix B.

The following research questions were studied and analyzed to determine the strength of the stated hypothesis:

1. How is dimensional analysis currently explained in most high school chemistry textbooks, with respect to student's conceptual and visual understanding?

   The researcher collected the chemistry textbooks currently used in the participant schools as well as other textbooks used by other teachers in the State of Tennessee. More specifically, the researcher focused on those chapters and/or sections that pertain to dimensional analysis. The researcher also included all textbook problems that are at the end of the dimensional analysis section and/or chapter for further review to determine what specific learning goals the author(s) intended for the students to learn after completing that section/chapter. The researcher used the modified version of Forsten, Grant and Hollas (2003) textbook evaluation to record the data (see Appendix P).

(a). What supplemental material is typically provided to enhance students' understanding of dimensional analysis?

The researcher requested participant teachers to provide any supplemental materials they used to help students grasp the concept of dimensional analysis. This helped the researcher better understand the teacher's concept of effective curriculum development with respect to dimensional analysis. Many students typically use online resources to aid them with their homework or to prepare for exams. Since the main focus of this research investigated the effectiveness of the supplemental use of web-based materials, the researcher also reviewed web resources. Evaluating these websites provided the researcher with a more holistic view of all the supplemental materials today's high school teachers and students use to enhance understanding of dimensional analysis. The researcher used the web site evaluation form found in Appendix Q to record the data.

(b). What effect does this material have on student understanding?

The researcher used the interview questions found in Appendix O to collect teachers' perspectives on the effects textbook and supplemental materials have on a student's understanding of dimensional analysis. The researcher used the survey found in Appendix M, as well as interviews (Appendix L), to obtain the students' perspectives on the effects of using the supplemental material provided to them—or from materials they sought independently via the Internet—with respect to their conceptual understanding of dimensional analysis.

2. What are the textbook related difficulties high school students have with conceptual understanding of dimensional analysis?

   The researcher conducted open-ended interviews with the participant teachers, using the questions listed in Appendix O. The students were also asked questions about their views of the textbook, shown in the pre-survey found in Appendix M.

3. How does the supplemental use of a proprietary interactive software program affect a student's conceptual and visual understanding of dimensional analysis?

   The Conversionoes software has several elements that assessed student's conceptual (Dimensional Analysis) and visual understanding (Smaller or Larger). The researcher interviewed students using the interview questions provided in Appendix L, which addresses visual and conceptual understanding of dimensional analysis. The researcher used the data generated by the software, as well as the qualitative data, to help ascertain students' conceptual and visual understanding gains in dimensional analysis.

4. What effects does the software program have on students' perceptions of the process of dimensional analysis and their ability to grasp the logic behind it?

   Science researchers have observed a strong correlation between perception toward science and achievement in science studies (Cannon & Simpson, 1985). A mixed method approach was used to address this question. A five-point Likert survey was used to determine students' conceptual and visual understanding. Students were asked questions on their perception of their visual and conceptual understanding of dimensional analysis via the pre- and post-surveys found in Appendices M and N. Student participants were randomly chosen randomly chosen for the control and treatment groups based on the selection criteria to ensure the student participants reflected the demographics of the class (race, gender, socioeconomic status and academic standing). A stratified, purposive sampling was used to create the interview groups to reflect the class demographic and student were interviewed using the questions provided in Appendix L. In addition, students were observed while they were using the software with the aid of a modified version of Northwest Regional Educational Laboratory's (2004) observation rubric (Appendix O). This data helped capture student interactions with the software and with each other while solving dimensional analysis problems.

5. How does the addition of the software change the students' chemical dimensional analysis problem-solving proficiency?

Teachers generally administer some type of formal assessment to determine their students' understanding of the content presented. The researcher administered a pre-test and post-test (shown in Appendix I and Appendix J, respectively) to help determine the possible affects the software had on student's conceptual understanding. The questions used in the pre-test and post-test were in the same format that the treatment group of students experienced while using the software. Quantitative data was gathered from the test in the form of numerical data (close-ended items) to determine raw scores and comparisons. The pre-test and post-test were given to two groups in the same class of the participant teachers. The groups consisted of the control group (those not using the software) and the treatment group (those using the software) to get a baseline on the true effects of the software on student learning. To compare the pre- and post-test results of both the treatment and control groups, equivalency scores were calculated. The test required students to show their work prior to selecting their final answer. This aided the researcher to better understand how students solve dimensional analysis problems.

Pre and Post Test

As discussed above, a pre-test and post-test were developed by the researcher and distributed to the participants. Both the treatment and control groups were given the pre-test after traditional lecture and textbook instruction. Each group was given the post-test after they received supplemental intervention via the software or the alternative in-class worksheet activity found in Appendix R. A sample of the pre-test and post-test can be found in Appendix M and N, respectively.

The tests were evaluated with the rubric shown in Figure 13 below.

	6	**4**	**2**	**0**
Dimensional Analysis Pre- and Post-Test Final Answer Completion	Right Answer, Proper Units, Proper Significant Figures, Proper Scientific Notation	Proper coefficient/base unit, Proper Units, Proper Significant Figures or Scientific Notation	Proper coefficient/base unit, Proper Units	Wrong Answer, No Answer

Figure 13. Pre- and Post-Test Grading Rubric.

The rubric was designed to capture the requirements of the Conversionoes software that students must meet to receive the feedback of "Correct" and credit towards their level certification (at least 90% accuracy), answer in proper significant figures, scientific notation, and units. Full credit (6 points) was given to those answers that meet all of the requirements and would be the only answer acceptable in the Conversionoes software. An answer that had the proper coefficient/base number, proper units and significant figures or scientific notation received 4 points. An answer that had the proper coefficient/base number and proper units received 2 points.

No points were given to incorrect answers or answers without proper units. Examples of answers with respect to points are as follows:

1. 2.02×10^{-2} m -6 points (proper significant figures, scientific notation and units)
2. 2.023×10^{-2} m -4 points (proper coefficient/base units, scientific notation and units)
3. 0.0202 m -4 points (proper coefficient/base unit, significant figures and units)
4. 0.0203 m -2 points (proper coefficient/base unit and units)
5. 0.00203 m -0 points (wrong answer)
6. 0.0202 -0 point (no units)

The researcher reviewed the rubric along with the examples above and confirmed with both participant teachers that they use a similar rubric to grade dimensional analysis problems. In an effort to ensure the tests were graded fairly the researcher had the graded test reviewed by two high school chemistry teachers (not the participant teachers) for accuracy. The original grades recorded by the researcher were confirmed as fair with respect to the rubric criteria.

Observations

The students were observed by the researcher while they were using the software through the aid of a modified observation rubric created by Northwest Regional Education Laboratory. Extensive field notes were taken during that time using the observation rubric created for this project to enhance the overall analysis. Observations were not a major portion of this research but the researcher felt student interaction with the software should be captured and would help strengthen the data thus structured observations were utilized. The researcher used a closed-ended instrument during observations that focused on pre-test coded attitudinal actions and interactions with the software. Observations were made in twelve minute intervals, and were conducted three times in total per treatment group. A sample of the form used during the observations is shown in Appendix O. During the observations the researcher functioned as a participant-observer, mainly because she had to serve as the instructor for the treatment group while the students were using the software and the teacher participants worked with the control group on their in-class assignment.

Interviews

The 12 students participating in the structured interview (Southerland et al., 2005) were varied in skill level in order to obtain the best representation of student conceptual and visual understanding of dimensional analysis prior to and after the educational technology integration. The students in the study were interviewed prior to taking the pre-test. Students were also interviewed after their use of the supplemental software. Final interviews were conducted after the post-test. The interview protocols are included in Appendix P. Each interview was digitally recorded and transcribed by the researcher.

The students that participated in the treatment group from School A were an African-American male, a White female, and a White Male. The control group from School A consisted of an African-American female, a White male, and a White female. The students that participated in the treatment group from School B were two White males and one White female. The control group contained two White females and one White male.

Survey

A five-point Likert-type confidence survey (5 = Strongly Agree; 1 = Strongly Disagree) was created by the researcher and used to assess the students' perception of the process of dimensional analysis and their ability to grasp the logic behind it. It was administered to both the control and treatment groups prior to the pre-test and after the post-test. The post-test survey included additional questions to assess students' view of the software and its individualized effect upon enhancing their conceptual and visual understanding. The survey also included questions to better understand student's perception on dimensional analysis problems. A sample copy of this survey can be found in Appendix Q.

Mixed Method Sampling Procedure

As discussed earlier, the sample of convenience for this study was comprised of two groups of students from general chemistry classes taught by the instructors at School A and B in the Chattanooga, Tennessee, metropolitan area. A stratified, purposive sampling of six students from each teacher was used for the interview portion of the data collection. The students represented a cross-section of the class, with respect to gender, race and academic achievement levels. The selection criteria included the current grade earned in the course, current overall grade point average, and teacher recommendation and student willingness to participate to ensure the group was as diverse as possible (including students with an A average, B-C average, and a C-D average in each group).

Mixed Method Analysis

The data collected by this study was both qualitative, in the form of interview transcripts, observation field notes, and documents (e.g., textbooks and worksheets), as well as quantitative, which included pre-test and post-test results and survey results. Appendix C, Table 6 summarizes the variables, data analysis instruments and the techniques used to address each research question, which is also detailed below.

1. How is dimensional analysis currently explained in most high school chemistry textbooks, with respect to student's conceptual and visual understanding?

   The textbook evaluation rubrics used in the data collection process were analyzed by the use of constant comparative analysis. The information gathered was summarized and written in narrative form. The narrative data was evaluated through the two general processes of constant comparative analysis: unitizing and categorizing. The following questions were addressed:

a. What are the similarities/differences in how the author's define dimensional analysis?
b. How is the problem solving process of dimensional analysis described and demonstrated?
c. What images are used to help students visualize units of measurement?
d. What are the similarities/differences in curriculum development of the supporting elements of dimensional analysis?

2. What are the textbook-related difficulties high school students have with conceptual understanding of dimensional analysis?

   The researcher transcribed all digitally recorded interviews. The researcher analyzed the transcriptions and looked for emergent themes. Finally, the researcher conducted a constant comparative analysis of all of the interviews to find the overall emergent themes from all of the participants. In addition, the researcher used student survey statements on questions pertaining to their views on the current textbook.

3. How does the supplemental use of a proprietary interactive software program affect students' conceptual and visual understanding of dimensional analysis?

   Student interviews were transcribed and emergent themes were used in the analysis of student conceptual and visual understanding. The data generated by the software for the Smaller or Larger and Dimensional Analysis elements of the software were analyzed to help strengthen the data set.

4. What effect does the software program have on students' perceptions of the process of dimensional analysis and their ability to grasp the logic behind it?

The researcher quantized all survey data and conducted an independent t-test for comparison of survey statements to determine if the software significantly affected the treatment groups' perception of their dimensional analysis problem solving ability. A 95% confidence interval level of difference was used to determine if a significant difference occurred. The researcher analyzed the data collected from the three observations taken at each school and looked for emergent themes between the two schools to better understand (1) how students used the software, and (2) if the software achieved its goal of improving visual and conceptual understanding.

5. How does the addition of the software change the students' dimensional analysis problem-solving proficiency?

   Achievement tests (pre-test and post-test) were analyzed using an independent t-test (Hinkle, Wiersma, & Jurs, 1998) to determine if a statistically significant difference between achievement pre-test and post-test scores for the treatment group was evidenced. A 95% confidence interval level of difference was used to determine if a significant difference occurred. A comparison was also made between the pre-test and post-test score differences between the control and treatment groups.

All data gathered from the student participants was subjected to a quantitative analysis by assigning a ranking to student comprehension at the interview stage of the study. The formative assessments (post-test) also went through a thorough quantitative analysis by assigning a raw score to each participant based on the pre- and post-test rubric criteria. These scores were recorded as the study progressed to determine evidence of growth by an increase in correct responses (according to the specific rubric criteria). All qualitative data from both schools was combined to create one data set for the control and treatment group to increase the sample size to strengthen the possibility of detecting difference.

All observations field notes and interview transcriptions were created and analyzed by the researcher. The researcher looked for emergent themes in the data and quantified that data once these themes have been identified. To validate the themes, the instructor consulted with the teachers and participants to ensure that all data was collected and represented accurately.

To properly analyze the test and survey results an independent t-test was used to assess whether the means of the two groups were statistically different from each other. This type of analysis was appropriate for this study since the goal is to compare the means of the control and treatment groups and was especially appropriate for a post-test two-group randomized experimental design. The researcher used SPSS to conduct the independent t-test and analyzed the generated output (t value, degrees of freedom, and p-value in particular) to determine if the means between the two groups is significant. If the data confirmed a significant difference then it will be safe to conclude that the difference between the means of the two groups is different (even given the variability), furthermore being able to conclude the treatment has made a significant impact on enhancing student learning and/or perception. If the output does not indicate that a significant difference occurred then the researcher must conclude that the software did not enhance learning and/or perception.

Mixed Method Inference Process

"Mixed methods studies frequently require mixed methods sampling procedures so as to simultaneously increase inference quality (internal validity and trustworthiness) and generalizability/transferability" (Tashakkori & Teddlie, 2003, p. 362). The researchers added that in order to accomplish that goal, "there is often a need for two types of samples: a probability sample (to increase generalizability) and a purposive sample (to increase inference quality)" (p. 363). To minimize alternative explanations to the cause-effect relationship of the software on enhancing student understanding Tashakkori and Teddlie‘s principles were applied wherever possible.

Validity

> In recent years many researchers have come to the conclusion that the most complete view of a student's conceptual understanding is probably obtained by using a combination of both qualitative methods (such as interviewing) and more traditional quantitative methods (such as traditional multiple choice exams) where the choice of the particular form(s) of each is tailored to fit the research question. (Smith & Southerland, 2008, Theory and Research sec., para. 6)

As other researchers have shown, studies employing multiple research probes have a high mode of validity and are more likely to adequately represents a learner's understanding (Songer & Mintzes, 1994; White & Gunstone, 1992).

External Validity/Transferability

In order to take a research data set and accurately generalize it to other people, settings, and times, external validity is vital (Cook & Campbell, 1979). One of the major areas of concern with respect to validity is sampling technique and size. The sample used in this study was identified by the researcher mainly due to convenience. To create a more representative sample, and consequently more generalizable data, the researcher would have to explicitly follow Tashakkori and Teddlie's (2003) recommendation of using not only a purposive sampling, but a probability sampling as well. In other words, using a convenience sample can limit the strength of generalizations. To counter this weakness, the researcher endeavored to do a thorough job of describing the research context and the central assumptions. By including this additional information in the final report, it is expected to provide those who want to extrapolate findings from a similar sample size/cohort a better understanding of how practical it might be to do so.

Internal Validity

"Internal validity is traditionally defined as what may be called 'causal validity' or one's justification in making a causal inference from one's data" (Johnson & Turner, 2003, p. 301). Patton (1990) stated that the researcher as the instrument is the greatest strength and weakness of qualitative methodologies. The credibility of the researcher, which is dependent on training, experience, track record, status, and presentation of self, must all be taken into account (Patton, 1999). As a skilled qualitative researcher one must be prepared to identify emergent themes, create codes and subsequently quantify them, ask probing questions, and know how to transition from participant to observer without jeopardizing the data. A skilled researcher will strengthen the validity of the data by providing more depth and breadth to the phenomena of interest. The researcher's past experience in conducting both large and small mixed-method studies—involving data collection and analyses—is expected to enhance the internal validity of the present study.

Trustworthiness

Trustworthiness is the extent to which an inquirer can persuade an audience that his or her findings are "worth paying attention to" (Lincoln & Guba, 1985). Several criteria are associated with trustworthiness—namely, transferability, dependability, credibility, and conformability (Lincoln & Guba). To ensure what Johnson & Turner (2003) termed "descriptive validity" (i.e., the factual accuracy of an account as reported by the researcher) is avoided and/or minimized, the researcher should have any accumulated descriptive data authenticated by participants. To address Johnson and Turner's interpretive validity (i.e., the degree to which the research accurately portrays participants voices), the researcher must set aside her own bias and let only the voices of the participants speak in the findings. To address Johnson and Turner's theoretical validity (i.e., the degree to which a theoretical explanation fits the data), the researcher must allow the theory to emerge from the data, rather than retrofit the data to fit a preconceived theory.

Triangulation

Gall, Borg, & Gall (1996), Patton (1990), and Tashakkori & Teddlie (1998) all discussed the principle of triangulations as a means of strengthening the “inference quality” (credibility or validity) of a study. Methodological triangulation, (Patton, 1990; Tashakkori & Teddlie, 1998), which is the use of several sources of data, was also employed using several types of qualitative and quantitative data. Both types of triangulation allowed the researcher to view the phenomena of interest from different perspectives, thereby enhancing the quality of the inferences that emerged from this study.

Limitations

This research was an exploratory study with limited generalizability due to the small number of students in the sample group and its purposive nature. Other limitations include the fact that the student participants from Schools A and B were taught by different teachers for different lengths of time (adding additional variables), as well as the fact that school demographic compositions were extremely different. The class, sample, and comparative sample included mainly white students, which also limits generalizability and eliminates the possibility of cross-ethnic comparisons.

CHAPTER 4-RESULTS AND DISCUSSION

Overview

This exploratory study evaluated the conceptual and visual understanding of high school students' knowledge of dimensional analysis after use of the Conversionoes software. Themes were compiled and compared across treatments to create a general understanding of how utilizing the Conversionoes software impacted the treatment groups' learning and perception of dimensional analysis. Conversionoes was used to supplement learning and was introduced to students after they received traditional lectures on dimensional analysis and had weeks of applications via textbook problems, worksheets, and quizzes. Conversionoes were designed to enhance learning by reinforcing skills already taught and/or allowed students to learn content they did not originally comprehend during the initial lecture.

A mixed methods approach was used in the data collection and analysis, which included a variety of qualitative and quantitative techniques. The qualitative data used in this study included documents, interviews, surveys, observations, and web sites. Some data was both qualitative and quantitative—mainly post-surveys that contained open-ended questions, as well as observations and evaluations made using the rubric, which also allowed for comments. The quantitative data collected for this research included pre- and post-test and pre-and post-surveys. This wide variety of information sources facilitated the data triangulation.

In terms of timeframe, the research was conducted towards the end of the semester after the teachers had instructed the students on dimensional analysis, including a six-eight week period during which they were able to apply the skills. When the researcher began the study, both teachers and students were enthusiastic—the teachers were happy because their students still needed practice with dimensional analysis, and the students were excited to be able to use computer software in their general chemistry class. The researcher promised the control group that their activity would be "fun" as well, but would not involve a computer to help ease the possible tension between the two groups (see Appendix R for the Control Groups in-class activity).

This study focused on the five research sub-questions described earlier in order to determine the effects of the Conversionoes software on enhancing student conceptual and visual understanding of dimensional analysis, thus addressing the main research question. Each sub-question was carefully crafted to provide a holistic view of all of the elements that can affect the process of learning dimensional analysis.

Textbook Evaluation

The first question looked at the effects of textbooks on student learning of dimensional analysis, and more specifically, how dimensional analysis is currently explained in most high school general chemistry textbooks used in the State of Tennessee. The textbooks were specifically analyzed on how they addressed student's conceptual and visual understanding of the topic. Each textbook was required to address the Tennessee State Science Curriculum Standards for High School Chemistry I: 3221.Math.9…Select appropriate units, scales, and measurement tools for problem situations involving proportional reasoning and dimensional analysis (Tennessee Department of Education, 2007). To address this standard, the performance indicators for students are as follows:

1. Use conversion factors, dimensional analysis, and ratio and proportion to convert between quantities.
2. Express large and small numbers using scientific notation and perform calculations in scientific notation.

The textbooks were evaluated with the rubric found in Appendix P, which is similar to what most school districts, science curriculum superintendents/directors, school science department heads/chairs, and/or high school chemistry teachers use to evaluate textbooks. Special emphasis was placed on visual images and technology integration into the curriculum. The criteria that was used is as follows: 1) Content Accuracy, 2) Writing Style, Heading/Sub Headings, Captions and Labels, 3) Topic Sentences and Sections/Chapter Previews, 4) Extension Activities, 5) Page Layout, 6) Graphic Elements, 7) End-of-Section/Chapter Comprehension and Critical-Thinking Questions, 8) Recommended Reading, and 9) Web Site/Other Educational Technology Tools. In addition, general comments were recorded for each item where applicable and overall general comments were added at the end of every evaluation. The rubric ranked each category on a scale of 3 (overwhelming evidence) to 0 (no evidence). The maximum score a textbook could receive is a 46, for 100% competency.

The textbooks selected for evaluation included the textbook that was currently being used in high school chemistry classrooms in Hamilton County. The other three textbooks were books that were used in other Tennessee counties, which were borrowed from the University of Tennessee at Chattanooga's library. The four textbooks evaluated included the following: World of Chemistry by Zumdahl, Zumdahl, & Decoste (2002); Chemistry: Matter and Change by Dingrando, Gregg, Hainen, & Wistrom (2002); Chemistry by Wilbraham, Staley, Matta, & Waterman (2002); and Modern Chemistry by Davis, Metcalfe, Williams, & Castka, J.F. (2002).

At the time of this study, World of Chemistry was the textbook of choice at both of the participating schools. The chapter evaluated was Chapter 5: Measurements and Calculations. Overall, this book had a total score of 26 out of 46 points for a 57.78% competency rating based on the selected criteria. The rubric used to record the evaluation can be found in Appendix T. The major strengths of this book with respect to dimensional analysis-related topics are related to content accuracy, writing style, captions and labels, and topic sentences and sections/chapter previews. The book includes a discussion of dimensional analysis and all supporting elements (e.g. significant figures and scientific notation) as well. In general, however, this textbook appeared to be lacking in many areas, ranging from non-existent section/chapter summaries to only providing four dimensional analysis problems for students to solve. In addition, there were only two “critical thinking” questions (that were not high order) and only one extension activity for students to apply dimensional analysis to more advanced problems. It should also be noted that this textbook does not provide any recommended readings or include suggestions for auxiliary web resources to enhance student learning.

World of Chemistry describes the process of dimensional analysis as “changing from one unit to another via conversion factors (based on the equivalence statements between the units)” (Zumdahl et al., 2002, p. 132). It also provides general steps for doing conversions by dimensional analysis:

1. Step 1: To convert from one unit to another, use the equivalence statement that relates the two units. The conversion factor needed is a ratio of the two parts of the equivalence statement.
2. Step 2: Choose the appropriate conversion factor by looking at the direction of the required change (make sure the unwanted units cancel).
3. Step 3: Multiply the quantity to be converted by the conversion factor to give the quantity with the desired units.
4. Step 4: Check that you have the correct number of significant figures.
5. Step 5: Ask whether your answer makes sense. (p. 132)

In addition to delineating these steps, the authors demonstrate how to apply these steps in one-step problem examples (which are equivalent to Level 1 problems in Conversionoes) and multiple-step problems (similar to problems found in Levels 2 and 3 of Conversionoes). The textbook authors provide hints on problem-solving strategies in the margins of the textbook on topics such as proper use of significant figures (rounding), scientific notation and proper use of units. The explanations on how to solve the problems are thorough and they appear to be adequate.

Overall, even though the description of dimensional analysis was adequate, the supplemental activities provided were lacking. Another shortcoming is that the authors neglect to provide sufficient visual images to enhance student learning. In fact, the only images provided appear early in the chapter and only focus on showing students measuring various items. Although one cannot unequivocally claim that World of Chemistry is an unsatisfactory general chemistry textbook, this researcher would assert that it does a poor job of teaching dimensional analysis—and especially in addressing conceptual and visual understanding.

Chemistry: Matter and Change (by Dingrando et al., 2002) was the next textbook evaluated, with dimensional analysis discussed in Chapter 2: Data Analysis. Overall, the textbook had a final score of 42 of 46 points for a 93.33% competency based on the selected criteria. The rubric used to record this evaluation can be found in Appendix U. As indicated by its high competency rating, this textbook has many strengths and very few opportunity areas. To improve in these opportunity areas, I would recommend that the authors add additional critical thinking questions so students can see how to apply dimensional analysis in the real world and how it is an interdisciplinary problem solving skill. I would also recommend a more detailed recommended reading list for those who are interested in learning more about the topic.

The most impressive section of Chemistry: Matter and Change can be found in the extension activities, which provide additional help on dimensional analysis in the Math Handbook, found in the Appendix B on the textbook, as well as supplemental practice problems found in Appendix A of the textbook. Overall, the graphics are done well and are designed to enhance a student's visual understanding of units in particular. For example, Figure 14 (Figure 2-7 from the textbook p. 34) is designed to helps students visually see what a conversion factor looks like by showing how ¼ cup is equivalent to 4 tablespoons as well as to 12 teaspoons.

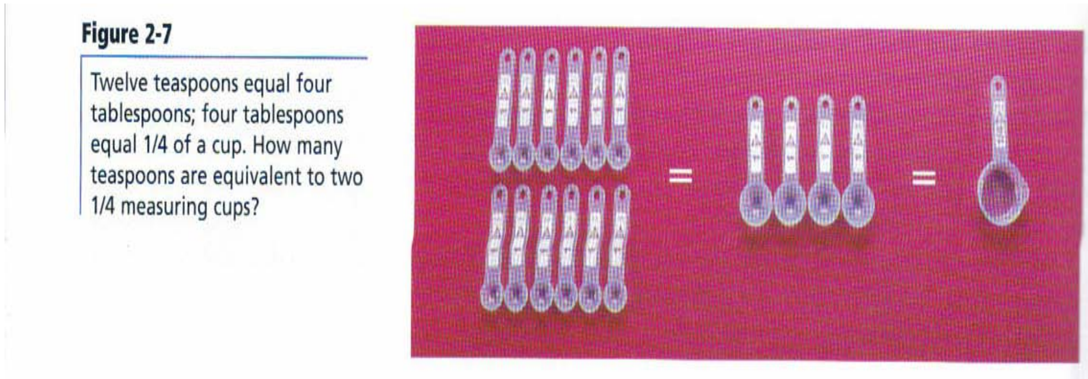

Figure 14[5]. Example of visual conversion factors found in Chemistry: Matter and Change, p. 34. In addition, this textbook provides web resources found at science.glencoe.com under measurements and data analysis, which focuses on the International System of Units, Scientific Notation, Significant Figures, and a web link to Convert It!, an online algorithm that converts various mathematical units. This website enables students to check their own final answers; however, this facility can only be useful if students are assessed on the entire problem-solving process, as opposed to only whether they arrived at the correct final answer.

Dimensional analysis is discussed in Section 2.2, Scientific Notation and Dimensional Analysis, and is defined as a "method of problem solving that focuses on the units used to describe matter" (Dingrando, et al., 2002, p. 34). The authors also defined dimensional analysis in the Math Handbook as, "the process of solving algebraic equations for units as well as numbers" (p. 900), and provided three general steps to solving dimensional analysis problems:

1. Analyze the problem-determine what conversion factors are needed to relate the given information to what is needed
2. Solve for the unknown-set up conversion factors
3. Evaluate your answer-to check your answer, you can do the steps in reverse order (p. 35)

The authors also demonstrate how students should solve dimensional analysis problems (similar to those found in Level 2 of Conversionoes).

5 Permission has been granted for the use of this image.

Although the textbook scored highly overall, the dimensional analysis section is not as thorough as it should be. The author only allocated two pages to the topic and provided one example of how students could apply the suggested problem-solving steps. One would have to assume, therefore, that the authors expected teachers to supplement this section with traditional lectures, coupled with the use of the provided supplemental materials to enhance a student's understanding of dimensional analysis.

Chemistry by Wilbraham et al. (2002) features a discussion of dimensional analysis in Chapter 4: Problem Solving in Chemistry. This textbook had the highest competency rating of 46 out of 46 points or a 100% competency rating. The rubric used in the evaluation can be found in Appendix V. As indicated in the evaluation, this textbook competently addresses every aspect under consideration. The most impressive aspect of the textbook is the authors' use of visual images that relate to real-world problems to further emphasize to students the transferability of dimensional analysis inside and outside the general chemistry classroom. The authors' skillful use of visual images should help student's conceptual and visual understanding of units and how they relate to conversion factors (Figure 15.)

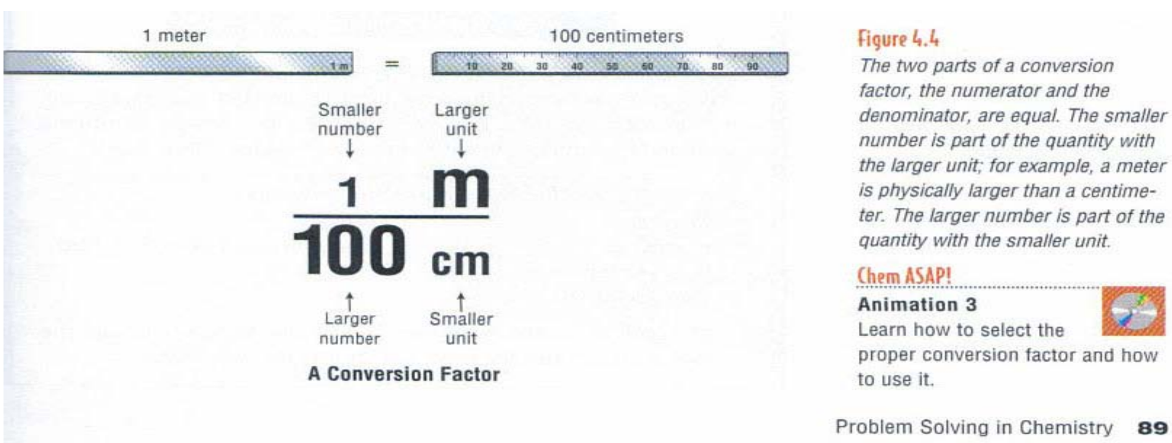

Figure 15[6]. Example of the effective use of images to show how units relate found in *Chemistry* p. 89.

[6] Permission has been granted for the use of this image.

In addition to well crafted textbooks, there are a number of excellent CD-ROMs available for students and teachers to use as supplementary materials. The student CD-ROM entitled Chemical Animations, Simulations, Assessment, Problem solving (CHEMASAP), contains simulations on conversion factors, allows students to create concept maps for the chapter, provides tutorials on significant figures, and includes several resources for students to check their comprehension of important ideas and concepts. The teacher CD-ROM, Resourcepro, has reviews, practice problems, quizzes, and suggested labs that all relate to dimensional analysis. There is also a designated place on the web for students to go for interactive quizzes to practice problems: www.phschool.com. A noteworthy portion of the text can be found in the End-of-Section/Chapter Comprehension & Critical Thinking portion of the analysis. The authors provide several opportunities for students to apply dimensional analysis problem-solving skills in problems that vary from small-scale labs (e.g. making accurate measurements and applying mathematics) to having students solve more complex open-ended problems.

The authors of Chemistry (Wilbraham et al., 2002) have essentially treated dimensional analysis as its own entity (unlike the other textbooks), placing related topics such as scientific notation in the previous chapter. In the other books, dimensional analysis was typically buried somewhere in between significant figures and scientific notation. This book treats dimensional analysis as a vital problem-solving skill, and begins the section by explaining how conversion factors are used in the real world and provides a practical example in the form of currency exchanges. The authors defined dimensional analysis in the text as, “a way to analyze and solve problems using the units, or dimensions, of the measurement” (Wilbraham et al., 2002, p. 90), while in the glossary of CHEMASAP they provided the following definition, “a technique of problem solving that uses the units that are part of a measurement to help solve the problem.” In addition, the authors described a technique for solving problems in general chemistry, which they conveniently break down into a valuable three-step problem-solving approach:

> Step 1: Analyze—list knowns and unknowns
> Step 2: Calculate—solve for unknowns
> Step 3: Evaluate—does the result make sense? (p. 91)

The textbook demonstrates how to implement this three-step problem-solving approach in numerous problems that help to imbed the technique. More importantly, they provide ample opportunities for students to apply this strategy in a variety of ways.

The final book evaluated was Modern Chemistry by Davis et al., (2002)—and in particular, Chapter 2: Measurement and Calculations. This book received a 34 out of 46 points for a competency rating of 75.56% based on the selected criteria. Overall, the text is well written with the exception of neglecting to add section/chapter summaries. The authors organize the content similarly to World of Chemistry and Chemistry: Matter and Change; and dimensional analysis is amongst topics such as accuracy and precision, significant figures, and scientific notation. The main element lacking from this text is depth. Although the authors address all relevant content according to the Tennessee State Standards, they do not provide extended learning opportunities for students to practice various types of problems. Nor do they provide a variety of example problems students can reference on how to apply problem-solving skills to dimensional analysis problems.

A prime example of the author's lack of depth can be found in the End-of-Section/Chapter Comprehension and Critical Thinking questions. The authors only provide four specific problems on dimensional analysis that are rather simplistic in nature. A fifth dimensional analysis example can be found in the web resources for the chapter, that only provides supplemental help with significant figures. Although the text scored high with the overall graphics, the authors failed to include any graphics in the dimensional analysis section of the text. The graphics used in other portions of the text scored well on the rubric, but they too seem to be lacking in depth and are hard to assess with respect to any value they bring in enhancing student visual understanding.

It should be noted that Davis et al. (2002) do not use the term dimensional analysis, but instead refer to the process as "deriving conversion factors," which they defined in subsection 2-2: Units of Measurement as "transforming a statement of equality to a conversion factor" (p. 33). In essence, the authors focus on helping students understand the relationship between the units they start with and the units they want to end up with via deriving conversion factors—also known as dimensional analysis. Similar to the Chemistry textbook (Wilbraham et al., 2002), Davis et al. (2002) include a general problem-solving technique that is consistent throughout the text, but theirs is a four-step approach (detailed below) versus a three-step approach.

> Step 1: Analyze—the first step in solving a quantitative word problem is to read the problem carefully at least twice and to analyze the information in it.
> Step 2: Plan—the second step is to develop a plan for solving the problem.
> Step 3: Compute—the third step involves substituting the data and necessary conversion factors into the plan you have developed.
> Step 4: Evaluate—examine your answer to determine whether it is reasonable. (p. 53)

Although the authors provide an excellent problem solving strategy, they only demonstrate how to apply it to one density problem.

Textbook Evaluation Summary

After conducting a constant comparative analysis of the rubric results the following questions were addressed to summarize the data:

1. What are the similarities/differences in how the author's define dimensional analysis?
2. How is the problem solving process of dimensional analysis described and demonstrated?
3. What images are used to help students visualize units of measurement?

4. What are the similarities/differences in curriculum development of the supporting elements of dimensional analysis?

After reviewing all four textbooks, it is clear that providing a problem-solving strategy ranging from three to five steps is a major component to any effective dimensional analysis content delivery. The major steps should include:

Step 1: Read and Analyze—define the knowns, define the unknowns, create a strategy (choose the appropriate conversion factors).

Step 2: Calculate—set up the problem and solve for the unknown.

Step 3: Evaluate Your Answers—check to see if your answer makes sense, make sure your have the proper units.

Most authors defined dimensional analysis with respect to unit conversions and the relationship between units. The examples they provided consisted of at least one instance of how to apply the given problem-solving strategies. Every author seemed to ascribe to the pedagogical philosophy that establishing a knowledge base of significant figures and scientific notations should precede the learning of dimensional analysis, since they are skills that are needed for determining a final answer.

With respect to visual understanding, the textbook authors varied on how to effectively use images to help enhance student learning. The most effective images focused on helping students see the relationship between unit conversions. Based on this assessment, the researcher incorporated all of these key elements (i.e., suggesting problem-solving strategies, creating lessons on scientific notation, determining significant figures, and effectively using imagery) and applied them in the design of the curriculum for the Conversionoes software. The handouts that supplemental the video tutorials can be found in Appendices BB-EE.

Supplemental Materials

To address the first sub-question on how supplemental material is typically provided to enhance students' understanding of dimensional analysis, the researcher focused mainly on evaluating websites used by teachers and students to enhance understanding. The criteria for selection was based on recommended procedure provided by teachers and students on selecting adequate web sites to support learning of dimensional analysis. During their interviews with the researchers, the teachers and students described their strategy for finding supplemental resources on dimensional analysis on the web. Using Google, they would type the key words "Dimensional Analysis" and investigate the first four websites that appeared—unless one of the four was Wikipedia.com, which teachers, especially, seemed to mistrust. However, the other sites they selected appeared to provide sufficient information to enhance learning, particularly for students having difficulties with a problem and needing a quick example to refer to while working on homework or studying for an upcoming test. Both of the teachers who participated in this study confirmed the usefulness of the "four-site Google search strategy," adding that they did not feel it was a need to create a more sophisticated search technique.

The researcher used the website evaluation rubric found in Appendix Q based on the following criteria: 1) Content Accuracy, 2) Responsible Author, 3) Credentials of the Author, 4) Student Engagement, 5) Conceptual Understanding, 6) Visual Understanding, 7) Tutorials, 8) Page Layout, 9) Graphic Elements (photographs, illustrations, maps, charts, etc.), 10) Drill and Practice, 11) Feedback, and 12) Functionality. In addition, general comments were recorded for each item where applicable and overall general comments were added at the end of every evaluation. The rubric ranked each category on a scale of 3 (overwhelming evidence) to 0 (no evidence). The maximum score a website could receive was 39, representing 100% competency. The following four websites were evaluated:

Alan’s Chemistry Page (http://chemistry.alanearhart.org/)

Chemistry, the Science in Context Chapter 1: Dimensional Analysis (http://www .wwnorton.com/college/chemistry/gilbert/ tutorials/ch1.htm)

The Port of Long Beach’s lesson on Dimensional Analysis (http://www. scribd.com /doc/7868914/Dimensional-Analysis)

Math Skills Review-Dimensional Analysis (http://www.chem.tamu.edu/class/fyp /mathrev/mr-da.html)

The first website evaluated was Alan’s Chemistry Page, which is a tutorial on dimensional analysis. Overall, the website scored a 25 out of 39 points or a competency of 64.10% based on the selected criteria. The website is broken down in eight parts, Part 1-Basic, Part 2-Setting Up Conversion Problems, Part 3-Basic Conversion Problems, Part 4-Complex Conversion Problems, Part 5-Dissecting Conversion Problems I, Part 6-Dissecting Conversion Problems II, Part 7-Density, and Part 8-Quizzes. Users may start at any point in the website and focus on any area of interest to them. The main objective of this website appeared to be aimed at providing students with tutorials on how to apply dimensional analysis problem solving skills. As such, Alan’s Chemistry Page does a good job addressing content accuracy, conceptual understanding, tutorials, drill and practice and feedback components of the rubric. It also provides users with an effective variety of examples on how dimensional analysis is applied in the real world. For students wishing to see how they did on the website’s quizzes, it delivers immediate feedback to help learners determine their proficiency in solving dimensional analysis problems.

Alan’s Chemistry Page, however, was somewhat disappointing with respect to the author’s credentials, visual understanding, graphic elements, and functionality. As an example, to authenticate whether the information was derived from a creditable source, the researcher attempted to locate information about the author (other than his name) on the website, but was unsuccessful. Additional research was needed to eventually determine that Alan's Chemistry Page was developed by Alan D. Earhart, a chemistry instructor at Southeast Community College in Lincoln, Nebraska. Another shortcoming of this website was the way in which some visual images were depicted. In fact, the only visual images used on the site showed how units cancel (i.e. a simple dash through the lines), as shown in Figure 16.

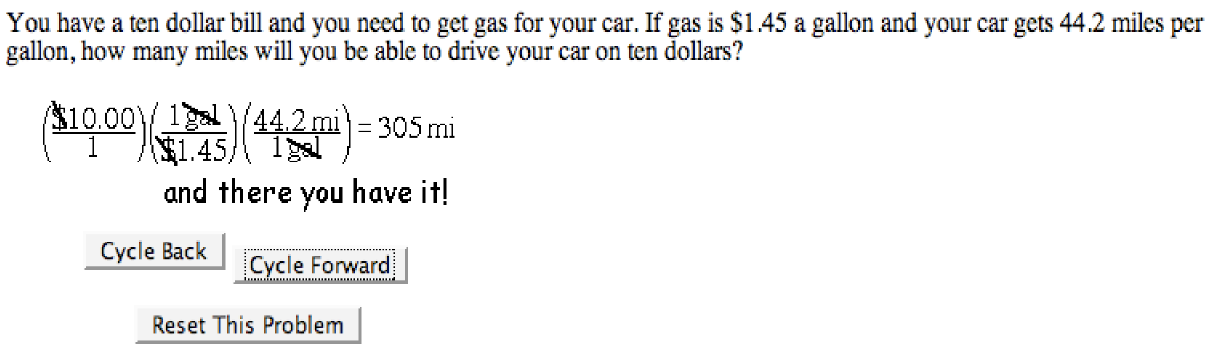

Figure 16[7]. Sample of images used on Alan's Chemistry Page.

Although all links worked, some of them did not have effective navigation strategies to get back to the previous page other than clicking the Back button of the Internet browser, which can be frustrating for some users.

The next website evaluated was Chemistry, the Science in Context Chapter 1: Dimensional Analysis, which is a web resource for a textbook written by Gilbret, Kirss and Davies (n.d.) and serves as a tutorial on how to solve problems. The user goes through a series of modules to learn how to solve dimensional analysis problems and then is allowed to practice what they have just seen demonstrated in the practice questions provided at the end of the tutorial. The practice problems are interactive and allow the user to click and drag the appropriate conversion factor to solve the problem. This website had overall score of 23 points out of 39 or a 58.97% competency rating based on the criteria used.

[7] Permission has been granted for use of this image.

The main strengths of this website were found in the content accuracy, conceptual understanding and tutorials, which were the main purpose of this website. The tutorials provided to students are excellent and the variety of problems presented allows students to see how to apply dimensional analysis in numerous settings. The practice problems that followed the tutorials were clearly designed to reinforce what was taught in the tutorials. The problems were designed around choosing the appropriate conversion factor to yield the final answer, which was given. The designers of this web-based tutorial were more focused on making sure students understood the relationship between the conversion factors with the given information, as opposed to determining if students could calculate the final answer. An example of a practice problem given in this website can be seen in Figure 17.

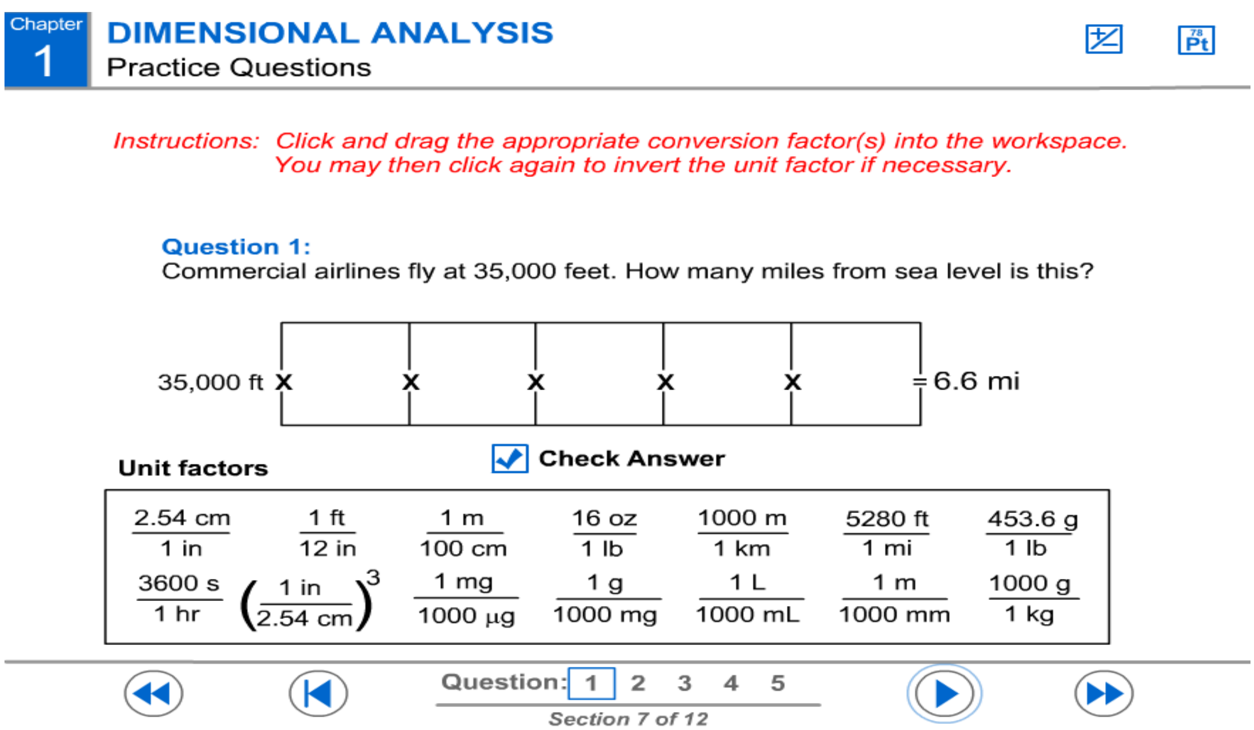

Figure 17[8]. Example of a practice problem in the Chemistry: Dimensional Analysis tutorial.

The biggest weakness associated with this website was its lack of visual images used to help students see the real world applications of dimensional analysis. The researcher also felt that

[8] Permission has been granted for use of this image.

the variety and number of practice problems were limited and did not allow students sufficient opportunities to reinforce the information they learned in the tutorials. The researcher also felt that there should have been a few problems that required students to enter their final answer, since as a rule students will be assessed on the entire problem solving process—not only for determining the proper relationship between units. Overall, the stated objective of this website, which was to help students learn how to keep track of the units associated with numerical values, was accomplished. The tutorial included detailed examples and interactive practice problems that allowed the student to better understand the relationship between conversion factors.

The Port of Long Beach (PLB) California's Community Development division created the third website evaluated, which appeared to be intended to make students aware of the Port of Long Beach and to prepare them for port career opportunities. Their lessons combine real-world PLB situations with content from the California state-approved curriculum. Specifically, the website provides an engaging and interactive series of lessons that fully conform to the state content standards while getting students excited about the major global seaport right in their own backyards. The PLB created a PowerPoint presentation that has been placed online on dimensional analysis that was evaluated for this study.

The PLB website on dimensional analysis had overall score of 23 points out of 39 or a 58.97% competency rating based on the criteria used. The major strength of this website was the content accuracy and the real world implication (even though they were biased towards one industry). Once students finish a tutorial and the accompanying supplemental worksheets, they could clearly see that dimensional analysis is a concept that is used daily with respect to importing and exporting goods in their community, and thus is a concept that is used inside and outside of the formal classroom. PLB's effective use of visual images could also help students understand the relationship between conversion factors used in the sample problems, as seen in the Figure 18.

Figure 18[9]. Example of images used in the Port of Long Beach's web lesson on dimensional analysis.

Although the website met its objectives of effectively explaining the process of dimensional analysis by using import and export examples, it was initially hard to determine who authored the website. The researcher had to conduct several searches to find background information to determine if the organization was creditable. In fact, it is still not clear who developed the education material in this website. It is clear, however, that the author(s) of this material wanted to ensure that all the content addressed specific California Science Standards and documented the correlation in the supplemental teacher's guide.

The final website evaluated was Math Skills by Dr. Wendy Keeney-Kennicutt, from the Department of Chemistry, Texas A&M University. Since the author's full credentials were not disclosed on the website, the researcher had to conduct additional research to determine her background. It appears that Dr. Keeney-Kennicutt is a chemical educator whose research interest are in chemical education, cooperative learning and the relationship between teaching methods and student learning success.

[9] Permission has been granted for use of this image.

Math Skills had an overall score of 15 points out of 39 or a 41.67% competency rating based on the criteria used. The overall objective of this website was geared to providing a review of how to apply dimensional analysis to typical problems students will encounter in general chemistry. The author provided six examples of customary problems that require the use of dimensional analysis, (also known as "common conversion"), one of which is shown in Figure 19.

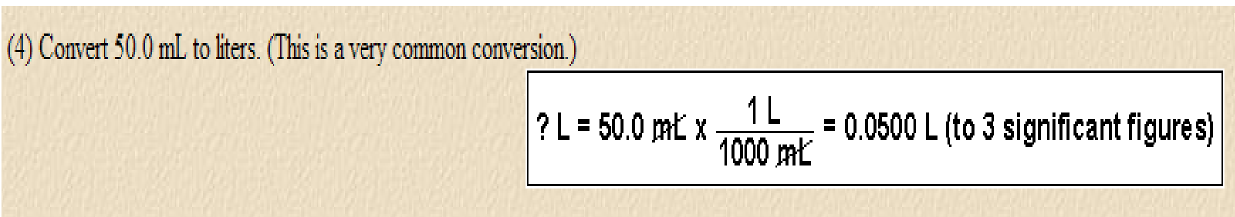

Figure 19[10]. Example of a common conversion problem student's will solve in general chemistry found on the Math Skills website.

If this website is primarily used as a quick reference, then it will serve students well. However, if a student is looking for a detailed explanation of dimensional analysis and how to apply it, this website falls short. Math Skills does not have much depth or breadth, thus lacking in many areas on the rubric.

Website Evaluation Summary

After reviewing all four websites, it was clear that in designing the Conversionoes software the website had to meet and or exceed the evaluation rubric that was used. To enhance student's conceptual and visual understanding of dimensional analysis, the researcher had to do more than simply show how units cancel. Students should be able see units in a practical sense to help them relate units to things they encounter in their everyday life. Human constructivism research supports the efforts of the Port of Long Beach website—that if students have a real world connection to the material, it will help them with meaning-making (Mintzes, Wandersee

[10] Permission has been granted for use of this image.

and Novak, 2005a). In fact, students agreed that the PLB website was particularly useful in helping with homework assignments since it included pictures of real items to help them understand problems. Despite this plus, the researcher believes that the Port of Long Beach website would be even more effective if the examples chosen had more practical applications to all students—not just those living in or around Long Beach, California. The participating teachers felt all the websites could be useful in reinforcing their in-class lectures. They added that they wished their students would use them when they got home to help them better understand the concepts covered, especially in areas where the textbook was lacking.

Effect of Textbooks and Supplemental Material Have on Student Understanding

The two teachers in this study freely identified the resources they typically used to help their students learn how to solve dimensional analysis problems. These included website suggestions, textbook handouts, and a sample worksheet (the latter two can be found in Appendices S and AU, respectively). The teachers stated that the resources provided by the textbook, World of Chemistry, were extremely limited and did not provide enough practice problems. The teachers admitted during their interviews that they preferred to use handouts similar to the one found in Appendix AU. Although both teachers advised students to use online resources when and where needed to augment material in the textbook, they both agreed that no single website could address all of their students' needs.

When the two teachers learned about the proposed software and all the features it contained, they were very excited, stating that they would use it to enhance their student's learning—as long as the study results were positive. Both teachers stated they were always looking for new ways to engage their students, since their customary use of supplementary paper worksheet did not seem to be as effective as it used to be with today's students, who require more technological stimulation. They agreed that Conversionoes had the potential to be a great solution to their pedagogical needs.

Textbook Difficulties

Teacher Perspectives

The participant teachers were interviewed using the interview protocol questions provided in Appendix O. Throughout the interview process, the responses from the two veteran teachers were remarkably similar. Although at the time of this study the teacher at School B taught at a school that was not as diverse as School A, she had previously taught for over 15 years at a school with similar demographics to School A in the Chattanooga metropolitan area. Thus, she relied on that prior experience in conjunction with her current experience to help enrich responses.

In terms of practice, both teachers typically introduce dimensional analysis with a lecture on units and start by introducing the metric system. They stated that this was “the easiest system to teach,” since the rest of the world is on the metric system and it encourages them to learn to convert “American units” into metric units. The only problem, they cautioned, was that some students have trouble with exponents. In other words, although students may set up a problem correctly, they forget how to multiply and divide with exponents. This was another theme that was discussed throughout the interviews. Both teachers lamented that the algebraic skills of many students were lacking and that they had a hard time transferring their algebra problem-solving skills to general chemistry because they thought they only had to use those skills in “math class and not science.”

Teacher A stated that on average it takes her students at least two weeks to grasp the concept of dimensional analysis. Teacher B noted that it generally took about two to three weeks for her students to grasp the concept. Both teachers agreed that students who do not grasp the concept in the allotted time become frustrated when they realize that the same problem-solving skills are needed throughout the remainder of the course—requiring them to go back and learn dimensional analysis in order to successfully solve problems such as molarity. Both teachers stated that they advise students to use web resources while at home to help them if they still do not understand the concept, which was detailed earlier in this document.

According to Teacher B, “Students have a hard time understanding the relationship between conversion factors, many times they just choose units because they want to make sure everything cancels but do not know why they cancel.” To help students better understand the relationship between conversion factors, both teachers attempted to use practical examples in the classroom—in the same way that the Port of Long Beach website used containerized cargo to teach dimensional analysis. Teacher A used a Krispy Kreme example to help students understand the relationship between units. She asked the class, “How many donuts are in a dozen?” Then she asked, “How many dozen donuts will I need if I wanted to buy donuts for this class?” Students quickly realize the suggested relationship: 1 dozen = 12 donuts. Thus, if there are x number of students in the class, they will have to divide that number by 12 to determine how many dozens are needed for the class. Teacher A added that using “soft numbers” like these helps students see that the “hard numbers” relate the same way as the donuts.

Teacher B noted that her students have a hard time conceptualizing units. Although she could not pinpoint the rationale behind this difficulty, she conjectured that this deficit could be attributed to a generation of students “whose imagination is not as vast as past students because they are not forced to create their own illusions, they are already had a computer generate it for them.” She recalled her surprise when she asked students to identify the smaller unit, a yard or a mile, and half of the class had no idea. She said she even told them to close their eyes and think about it and the results still did not change. Many of her students admit that they do not pay attention to labels, they just buy things and use them. She did notice that her female students had a better perception of size than her male students, especially when it came to food items because many of them were health conscious and were trying to watch their weight.

In discussing the textbook they used in class, both teachers expressed deep disappointment in the book overall, but especially with respect to the chapter/section on dimensional analysis. Teacher B said, “The current textbook is not good, in fact I hate it. It does not provide enough detailed information in general. I’m currently using the Chemistry textbook to teach from since we will be adopting it next year. The students however are forced to use the World of Chemistry as their reference when they work on their homework.” When asked about the supplemental materials provided with the textbook (see Appendix S), both teachers expressed their dissatisfaction and added that they would only use them for emergency lesson plans (lesson plans teachers create in the event they are unexpectedly absent). Overall, they agreed with the researcher’s assessment—that the textbook was lacking in depth and did not provide enough practice problems on dimensional analysis. They both stated that they used a worksheet similar to the one in Appendix AU. They said they try to provide students a variety of problems so they get used to the verbiage typically found in dimensional analysis problems, such as words like “express” or “convert.” They also like to use real world examples so students can see how dimensional analysis is applicable in their daily lives.

Student Perspectives

Students were asked in the pre-survey to state their perception of the following statement: My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures. The scale ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). Overall, there was not much variation between the average perception between the control and treatment groups and both ranged in the Somewhat Agree category. After collecting the post-test at both schools, the researcher conducted an impromptu focus group and asked the class (both control and treatment groups) their perception of their current textbook. At School A, the students quickly raised their hands and began expressing their disappointment with the text. One student said, “I don’t like it and neither does Mrs. X [Teacher A], she hardly uses it. We do a lot of worksheet stuff.” While this student was talking the rest of the class laughed in agreement. When I asked if they ever used their textbook as a reference when doing their homework, one student replied, “I never take it home unless I have to do problems out of the book. I just use my notes or the web to help me.” Other students expressed similar sentiments. One student said she liked the book and “didn’t see what the big deal was.”

At School B, the students were more apprehensive in voicing their opinions on the textbook. As a result, the researcher asked Teacher B to step out of the room to see if the students would feel more comfortable expressing themselves in a more private setting. This seemed to help break the ice because students quickly raised their hands to express their dislike for the current text. They said it was confusing, and that they didn’t see the point of using it if the teacher did not. When asked about the chapter on dimensional analysis, one student responded: “The problem solving steps and examples were the best part of the chapter, everything else was just OK.” Another student said, “There weren’t enough problems that I could work on to practice before the test.” Although this statement was followed up with a few laughs from their classmates, they eventually agreed that there were not enough practice problems. The researcher asked if they created their own problems to solve in order to supplement the book, and they laughed at that suggestion. One student said she uses the Alan’s Page website a lot to help her with her work. In fact, she stated that she “really likes how they break it down and they have tons of examples.”

Effect of Textbooks and Supplemental Material Summary

The interviews revealed that the current textbook did not adequately address the needs of students or teachers with respect to dimensional analysis, as evidenced by the fact that both groups felt the need to supplement the text via worksheets and/or Internet resources. Although the veteran teachers encouraged students to use the Internet to help them with their homework, they did not integrate any particular web resources into their lessons on dimensional analysis. When asked if they would like to do so, the teachers stated that if they had the time to evaluate web resources they would allow their students to use software to enhance their learning in class, since they have seen how technology can stimulate a student's learning. Students complained about the overuse of worksheets and strongly suggested that their teachers integrate more technology in the course for future students. In thinking about the various concepts taught in general chemistry, both teachers and students agreed that dimensional analysis was one of the most fundamental concepts in the course. Those that found it easy to grasp when initially taught felt they were better able to follow the remaining curriculum in the course. Conversely, those that struggled with dimensional analysis stated that they had to go back and learn how to solve the problems in order to pass the course.

It was interesting to note how similar these teachers' experiences had been with teaching dimensional analysis over a span of 20 years. They both stated that at times they wished they could have opened up their students' brains and turned on a switch that would allow them to "get it." They both said that one of the most rewarding aspects of their job was seeing the light bulb come on when students grasped concepts like dimensional analysis. They added that the look on the student's face is "priceless," and is why they both have continued teaching for over 20 years. The researcher had a similar experience when a student said she "got it" because of using one of the Hints videos. It was a very inspiring moment in a very stressful day.

Conversionoes Effect on Conceptual and Visual Understanding

The Conversionoes software features several elements that can assess a student's conceptual (Dimensional Analysis) and visual understanding (Smaller or Larger). The Smaller or Larger portion of the software contains ten questions requiring students to visualize which unit was Smaller or Larger (depending on the question) prior to seeing the images of the items (see Figures 20 and 21).

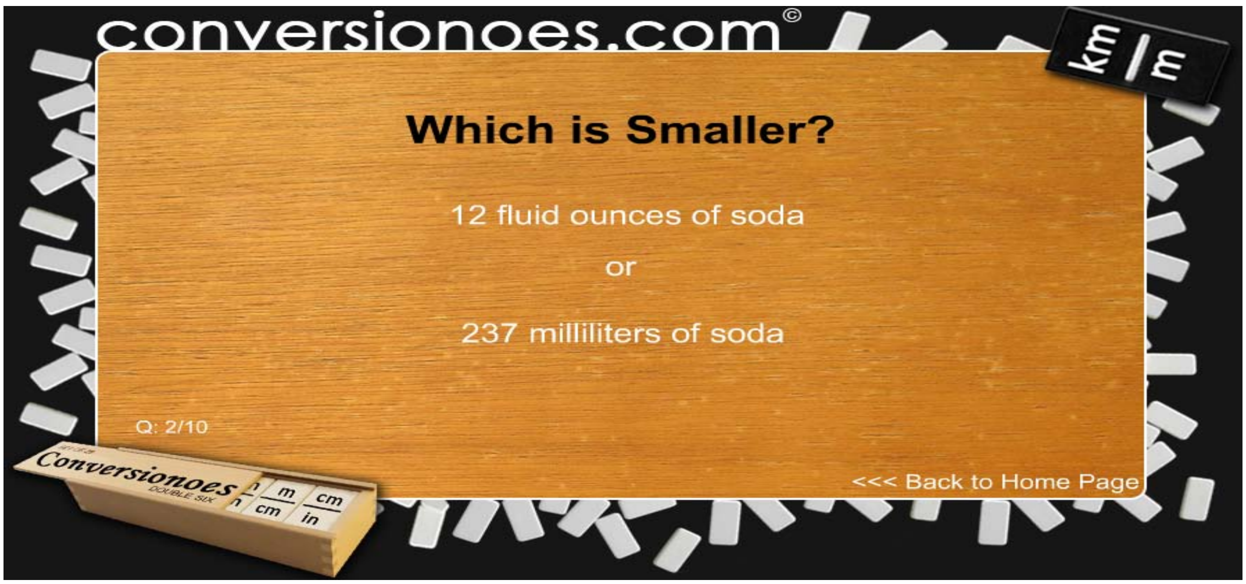

Figure 20. Smaller or Larger example problem.

Figure 21. Smaller or Larger Example Answer Screen.

The proficiency rating of the Smaller or Larger segment of the software of the two treatment groups at School A and B was 76.2% and 68.9%, respectively. During the initial use of the software, the researcher noted how several students talked to their computer and said “I knew the answer, I don’t know why I chose that one,”; “Yes!!”; “I got it right.”; or “Oh, man!” While using this portion of the software, students expressed their delight with actually being able to see the units. They said it helped them better understand what types of items are measured in the “those types of units.” Students could see what units were used in volume problems as shown in figures 20 and 21. One student in the interview said, “I didn’t know that there were different types of units on items like Coke, I only thought it came in ounces. I’m going to play this game with my parents to see if they can tell. It’s fun!”

The researcher asked students what effect did they think the Smaller or Larger segment of the software had on their overall understanding of dimensional analysis. They replied that it helped them think about the units and what they looked like. “It also makes units more real which made the problems seem real,” said a student from School B during their interview. Although students were not required to visualize units in the same way in their formal assessments (pre- and post-tests), they could transfer this same skill and add it to their problem-solving strategy to help them visualize the units being used in the problem. In so doing, they were able to determine if their final answer should be smaller or larger depending what information was given in the problem, as well as determine which conversion factors were applicable for the particular problem because, for example, they were able to quickly eliminate those factors that were not volume-based units.

During the 45 minutes students were allowed to use the software, the majority of their time was spend on the Dimensional Analysis portion of the software, which addressed student conceptual understanding. Students were able to complete Levels 1 and 2 of the formal assessments and had the following proficiency scores: School A Level 1: 64.62%, School B Level 1 25.56%, School A Level 2 70.00%, and School B Level 2: 25.00%. The researcher noted that a few students from School A were more inclined to work their problems out on paper to help them solve and double check their answers prior to submitting their final answer. Students at School A collaborated more to make sure their neighbor was able to solve the problems, while students from School B only discussed their answers after they submitted an incorrect answer and had to reevaluate the problem to determine where they made their mistakes. Although the proficiency levels at the schools were not equivalent, students spent similar time analyzing answers and the determining proper steps to produce the correct answer. Thus, students were still using problem-solving skills in order to evaluate how to arrive at a correct answer, instead of merely getting to the correct answer.

Another element of the Conversiones software that was designed to enhance student conceptual and visual understanding were the Hints. The researcher gave the students a brief overview of Conversionoes by taking them on a virtual tour of the software and explained each element, it was at that time students were told that the Hints were available for their use as a reference while they were solving the dimensional analysis problems to help them better understand how to properly solve dimensional analysis problems and all of the fundamental skills required in the process. For example, a student was observed prior to submitting a final answer used the significant figures video and returned to their problem and applied the skills they learned and successfully submitted their final answer. Although there were pdf files of the Hints, students preferred to watch the videos. The pdf files can be found in Appendix AB-AE. Many students said that they would only use the pdfs if they could not watch the videos. One student said, “if I don’t have to read I don’t, thanks for the videos.”

Interviews

The researcher interviewed students using the interview questions provided in Appendix L. These questions addressed visual and conceptual understanding of dimensional analysis. Six students were interviewed from each class, three from the treatment group and three from the control group. The teacher participants assembled the groups to be as diverse as possible with respect to the class demographics, academic standings of the students, and the limited pool of students that volunteered to participate in this portion of the study.

The interviews were conducted at random as to not inform the students of the academic ranking system. The researcher and teacher participants were fortunate that the student volunteers fit the ideal research criteria, and that the interviewee groups were somewhat diverse, given the limitations provided with the initial class creation. The students were reassured that their comments would be kept confidential. The researcher reviewed the consent forms with the students and their parents prior to asking them to sign them to ensure that they were fully aware of their rights as research participants. The students appeared to be comfortable with the interview and were very candid with their responses.

Pre-Treatment Interview

The pre-treatment interviews were conducted after the students had lectures from their participant teachers and had applied these skills for weeks on textbook problems, worksheets as well as on quizzes. During the interview, students were asked to perform similar tasks to those included in the Conversionoes software. Specifically, they were asked to look at two sets of units and determine which was smaller just by looking at the units. Once an answer was chosen, students were then shown the picture of the items to provide immediate feedback. Another question was asked where students had to choose the larger unit between the two listed and visual feedback was given after an answer was chosen (see Appendix L). During pre-interview testing, students in both groups had the same proficiency rating of 67.67%. Interestingly, more students in School A got the smaller question correct, while more students in School B got the larger question correct. This might be attributed to the fact that students in School A were more familiar with length units, compared to School B's students, who were more familiar with mass units.

The differences were most prevalent between the academic rankings of students in each respective interview group. The students who had the most success with this portion of the interview were the students who had earned a B or C average in general chemistry. When asked the questions they clearly took their time and thought about the units. One student in the treatment group from School A actually closed her eyes to "see" the units. After she had chosen the correct answer, I asked her to try to verbalize her thought processes. She replied, "I was trying to see if I could visualize the products and then think about the units to help me come up with my answer." She noted that having the units associated with products she was familiar with was very helpful—"It made the units come alive to me."

Surprisingly, the students that had the highest and lowest grades in general chemistry all got one out of two questions correct. The students who had the highest grades essentially admitted that they had rushed through the question, and that as soon as they saw the answer they realized they were wrong. The students who had the lowest grades in their respective groups all said that the smaller or larger images helped them better understand the units because they could relate them to a real object. They said the hardest thing for them to determine when they were solving problems was whether their final answer made sense. One student from School B's control groups said, "My teacher always tells me to check my answer to see if it makes sense and I just look at her because I don't know what I'm supposed to be looking for. Now I can see that if I can visualize the units to begin with I will know if my answer makes sense. For example, if I'm going from gallons to milliliters I will know my final answer must be large because it will take a lot of milliliters to make up a gallon. Why can't the book problems asked questions using items we know like your questions? It would make it easier for me to understand."

Students were also asked to solve two dimensional analysis problems and to orally explain the thought process they used to solve the problems. Overall, students enjoyed explaining their thought processes with the researcher. Many, in fact, were able to identify errors more easily simply by verbalizing the steps they took to reach an answer. The problems chosen for the interview were comparable to the problems used in Level 1 and 2 of the Conversionoes software. Students who had the highest grades in the class were able to solve the problems successfully; students whose grades ranged from B to D had the most trouble; while students in the midrange were able to set up the problem correctly, but all of them had one or two computational errors. The students with the lowest grades had more computational errors than any other group.

One student from School A said, "I didn't understand this when she taught it and I haven't been able to get it." When the researcher saw where the student was stuck, she tried to help him solve the two problems because she could feel his frustration level was starting to rise. Thus, the researcher thought it was more important to put the formal interview on hold and assist the student with trying to grasp the concept of dimensional analysis. Although the researcher was successful with helping him set up the problem, she was surprised to find out that the student did not know how to use a scientific calculator to do the final computation. As the researcher continued with the remainder of her interviews, she saw that this was an issue for several other students who had a C or D in the course. They could set up the problem correctly, but determining the final answer was a challenge. This also caused frustration for students who wanted to know if they got the correct answer, but were less concerned about the problem-solving skills needed for that correct answer.

Some students correctly set up a problem and were able to use calculators to help compute the final answer, but they neglected to put their answer in the proper significant figures and scientific notation. When students were asked about significant figures, they responded that they were able to determine them, and that they were able to put numbers in scientific notation. However, these students did not see how these two procedures were applicable to dimensional analysis. When the researcher brought this to their attention, one of the students from School B said, “That’s why I only get partial credit on these problems, I never put my answer in scientific notation with the proper significant figures. I always forget to do that. I just put the numbers in my calculator and write down what’s on my screen [calculator display screen] and move on to the next problem.” Many other students that produced this same error repeated this sentiment.

<u>Post-Treatment Interview</u>

Overall, students in the treatment group were extremely more confident in their dimensional analysis problem solving ability than their control group counterparts. Treatment group students had higher proficiency levels in the Smaller or Larger and Dimensional Analysis problem solving portions of the interviews. The proficiency ratings of the treatment groups on the Smaller or Larger portion of the interviews was 91.67% overall and the control group had an overall score of 83.33%. The treatment group student that answered said, “I knew the right answer but second guessed myself because I came up with the right answer too quickly and just thought I had to be wrong. Man!” The students from the control group that only answered one out of the two questions correctly fit each academic category. Their main reason for getting the problem incorrect was that they were thinking the opposite of what the question was asking. One student said, “I know you asked me which was smaller but I just picked the bigger one anyway, I don’t know why I did that.”

Overall, students in both groups said they liked having images to associate with numbers. Students in the treatment groups, in fact, stated that was one of their favorite parts of using the software. They liked being able to think about the units and then see a picture of items with which they were familiar. One student said, “I never realized that products had conversion factors on them.” Many students recommended that I tell their teachers to use Conversionoes next year because they think it will help other students. “I wish she would have used this [Conversionoes] when she taught us this [Dimensional Analysis]. I need to see stuff to help me learn. I never knew we use milliliters in real life. Knowing that Coke comes in milliliters might have helped me not think conversions were stupid.” When the control group heard about the treatment groups’ experience with the Smaller of Larger portion of the game, many said they were jealous because they like doing this in the interview. The student with the highest grade in the control group at School B said, “I like this, it’s like nerd fun.”

When students were asked to solve dimensional analysis problems, those students in the treatment group that performed poorly during the pre-interview appeared to be more confident. They were eager to talk about the steps they took to address the problem. The student that was extremely frustrated during the pre-interviews said, “I think I got this now. I used the software and even watched some of the hints. I didn’t understand significant figures when she taught it but now I do for real. Those videos really did help.” I asked the student if he felt they were too long and he replied, “Not for me, I didn’t understand so I need someone to take their time with me. If I wanted to speed it up I could just fast forward to the part I didn’t understand. They were perfect for me.” The student was successful in solving the problems and was able to explain each step in his problem-solving process to the researcher.

The Post-Treatment interviews allowed the researcher to assess student's problem solving proficiency of dimensional analysis problems, their ability to visualize units and student perception of dimensional analysis and all of the elements that affected their learning of the content. It was also at this time the researcher was able to request feedback from the treatment group student's on their impressions of the software. The researcher received and overwhelming positive response from all of the student evaluations. The researcher tried on multiple attempts to ask the treatment group students how the software could be improved and the students could not think of one thing the software did not address. The only suggestion was to allow students more time to use the software and to allow their teacher to use it next year. They all felt the software helped them either learn material they never grasped during the allotted time for that material or improve their dimensional analysis problem solving skills.

Student Perception on Dimensional Analysis

The pre- and post-surveys were administered before and after the treatment and/or in-class assignment. A five-point Likert-type confidence survey (5= Strongly Agree; 1=Strongly Disagree) was used by the students to record their perception of dimensional analysis. An independent t-test was run on the pre- and post-survey results. The null hypothesis for both tests was that no significant difference existed between group perceptions on dimensional analysis. Students were asked several questions on their perception of their visual and conceptual understanding of dimensional analysis in the pre-survey and post-survey found in Appendix M and N, respectively. In general, all students prior to the treatment assessed their level of conceptual and visual understanding as midrange, meaning they were somewhat comfortable with solving dimensional analysis problems and visualizing units.

Table 4 contains a list of questions asked in the pre-survey, with the corresponding numerical equivalents for the student responses:

Table 2
Raw data of pre-survey student perception results

Groups	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook of any handbook or worksheet.	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.	I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.	Presently I understand the relationship between conversion factors and how to use them to solve various problems.
Control A Average	2.73	3.27	2.82	4.00	3.36
Treatment A Average	2.64	2.73	2.27	3.36	2.91
Control B Average	3.00	3.00	3.00	3.67	3.50
Treatment B Average	3.38	3.63	3.38	3.86	3.63
Average	2.94	3.16	2.87	3.72	3.35
STD DEV	0.332	0.384	0.462	0.277	0.313

To determine if there was a difference between the control and treatment group perception of dimensional analysis an independent t-test was used. The null hypothesis assumed that there was no significant difference between the groups. The Levene's test indicates that equal variances are assumed (as evidenced by the F value not being significant at $p<0.05$). In this case, the results indicated the equal variances assumed data should be used in the analysis. Based on the p value ($p = 0.006$), the null hypothesis was rejected. Therefore, a significant difference with respect to perception of dimensional analysis was evident in the treatment group ($t(-2.934)$, $p = 0.006$). Finally, students in the treatment group developed significantly more positive attitudes than the control group, as shown evident in Table 5.

Table 3
Inferential statistics of student perception of dimensional analysis skills

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PRS3	PRS3 Equal variances assumed	6.356	.017	-.386	34	.702	-.124	.321	-.776	.528
	Equal variances not assumed			-.375	25.468	.710	-.124	.330	-.802	.555
POS3	Equal variances assumed	5.735	.022	-2.934	33	.006	-.853	.291	-1.444	-.261
	Equal variances not assumed			-2.892	25.504	.008	-.853	.295	-1.460	-.246

Dimensional Analysis Problem Solving Proficiency

The pre- and post-test (found in Appendix I and J) were administered on the first and last day of the study, respectively. The students were provided a conversion chart to help them focus on the problem-solving process versus trying to memorize various conversion factors. The students were familiar with the format of the questions from previous problems solved in textbook and worksheet activities. The participant teachers administered the pre-test and stated that the only questions they received was whether students could use their calculators, and if a conversion chart would be provided. The researcher was present for both post-tests and the only question asked was at School B, when the researcher noticed two students talking in the back of the classroom. The students were asked what they were discussing, one of them replied, “How do you put million in scientific notation, I forgot?” The researcher asked the student several questions about metric units to help jog the student’s memory. Finally she said, “I got it, it’s 10^6, I just had a brain fart.”

The post-test was a rearrangement of the pre-test, in that both contained similar questions used in Levels 1-3 of Conversionoes. Each test consisted of six questions; students were instructed to show their work on each problem they solved (see Appendix AS and AT). Students were given 20 minutes to complete the problems, and they had no problem completing the test in the allotted time. The tests from the respective schools were separated by group and graded by the researcher. The researcher analyzed both tests with the rubric shown in Figure 13. The maximum points possible available per test was 36 points, which meant that all answers contained the proper units, significant figures and scientific notation. Partial credit was given to answers that contained a proper coefficient/base unit, units, significant figures or scientific notation. No credit was given to wrong answers or answers without any units. The test grades were verified by high school chemistry teachers for accuracy and the original scores were proven to be acceptable and were deemed valid input data for the inferential and descriptive analysis.

The grades were recorded in a Microsoft Excel spreadsheet, which was used as the input data for the SPSS analysis (Appendix AW). The technique used to determine if a significant difference existed between the control and treatment group gains in dimensional analysis problem solving proficiency was an independent t-test. The null hypothesis stated that no significant difference existed between the pre-and post-test results of the respective groups. The results of the test have been summarized in the following table:

Table 4
Inferential Statistics for Pre- and Post-Test Data

Group Statistics

	Variable	N	Mean	Std. Deviation	Std. Error Mean
PreTest	Control	14	14.7414	8.04865	2.15109
	Treatment	14	15.9057	8.36987	2.23694
PostTest	Control	14	14.0321	13.81415	3.69199
	Treatment	14	29.3336	14.13868	3.77872

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pr	Equal variances assumed	.105	.748	-.315	26	.711	-1.16429	3.10340	-7.5434	5.214
	Equal variances not assumed			-.375	25.960	711	-1.16429	3.10340	-7.5438	5.215
Po	Equal variances assumed	.003	.959	-2.896	26	.008	-15.30143	5.28295	-26.169	-4.442
	Equal variances not assumed			-2.896	25.986	.008	-15.30143	5.28295	-26.160	-4.441

The null hypothesis assumed that there was no significant difference between the groups. The Levene's test indicates that equal variances are assumed (as evidenced by the F value not being significant at $p<0.05$). In this case, the results indicated the equal variances assumed data should be used in the analysis. Based on the p value ($t = -2.896$, $p = 0.008$), the null hypothesis was rejected. Regarding the difference between how the groups performed**, t**here was a significant difference between control and treatment groups. Thus, the individuals in the treatment experienced significantly better gains than the Control groups. From this data it appears that the supplemental use of the Conversionoes software did enhance student understanding of dimensional analysis.

It should also be noted that the researcher noticed that the treatment group students were putting their final answers in the same format required by the Conversionoes software—namely, in proper significant figures and in scientific notation, thus increasing the amount of points received per problem. The control group students seemed to follow the same pattern in the pre- and post-test. In other words, they put a random number of significant figures for their final answers and only used scientific notation for answers obtained from using their calculator, since the numbers were either too larger or too small to display on a normal calculator screen. While taking her exam, one treatment group student asked to borrow the researcher's scientific calculator so she could "solve for the final answer the easy way," since she only had a standard calculator that did not have a scientific notation function. The only instructions students were given was to show their work and to answer the problems properly. The researcher did not want to prompt the students to answer the problems in anyway she wanted to see if students would apply the new skills that they learned while using Conversionoes and was pleasantly surprised that they did and the statisical analysis helps support this visual observation.

Addition to the inferential statistics descriptive statistics were analyzed to determine who benefited more from Conversionoes software. The two areas that were under consideration were race (School A only) and gender (School A and B combined). Based on the descriptive statistics in Appendix AW it is clear that African-American students in general benefited the most from the software. African-American males had the highest increase in proficiency, 18%; followed by African-American females, 16%; White males, 10.22%; and White Females, 9.67%. Overall, females had the highest increase in proficiency, 15.59% and males increase on average by 12.42%. More importantly the software enhanced students of all ethnic groups and genders and helped them make gains in their proficiency levels of dimensional analysis problem solving.

Researcher's Reflections

The analyses of the textbooks and supplemental resources helped the researcher ensure that when applying the ASSURE model in the design of the Conversionoes software that all elements met or exceeded the criteria set in the evaluation rubrics. While considering the various potential design elements, the researcher constantly reflected on those documents to ensure that students could be effectively engaged with the content, and be provided the best material available to create an environment condusive for enhancing learning. The researcher was gratified that the hard work of trying to account for the smallest of details was noticed by the students and, in turn, helped increase their confidence in their own ability to solve dimensional analysis problems successfully.

The process of validating that the Conversionoes software made a siginificant difference in student's conceptual and visual understanding of dimensional analysis has been one of the most rewarding experiences in the researcher's academic life. Having the quantitative data to prove that the software helped students make significant gains, as well as the qualitative data to validate the software's effectiveness, has been monumental. The researcher was pleased to notice the difference in the treatment groups' post-tests, where the majority of students made a effort to put their final answers in the proper significant figures and scientific notation. This was further proof that students had learned the proper way to present their final answers based on the requirements of the Conversionoes software.

CHAPTER 5-SUMMARY, CONCLUSIONS, AND IMPLICATIONS

Summary

The following principal research question drove this study's design, execution, and analysis: Can supplemental use of interactive proprietary software enhance high school chemistry students' conceptual and visual understanding of dimensional analysis? The software was designed using the ASSURE model and was evaluated using the textbook and website evaluation rubrics used in this study—all with the goal of standardizing the quality level in curriculum and software development. All graphics and images used were created with respect to Tufte's principles of graphic design. The software, which was named Conversionoes, consisted of four major sections: Smaller or Larger, Dimensional Analysis, Conversionoes Game, and Hints (see Appendix A). Every element of Conversionoes was created and designed by the researcher and critiqued by general high school chemistry teachers and students in the Chattanooga Metropolitan area. To determine if Conversionoes enhanced student understanding, the researcher enlisted the help of two teacher participants, who divided two general chemistry classes at two different schools equally (with respect to demographics, socioeconomic status, grades, gender, etc.). The half of the class that used Conversionoes was referred to as the treatment group, while the other group was known as the control group. Students were given a pre- and post-survey as well as a pre- and post-test to determine the effectiveness of the Conversionoes software, as well as to ascertain student perception of dimensional analysis.

Six students from each class (three from each respective group), three females and three males, were interviewed before and after each test. They were asked to rank items, solve problems, and explain their problem-solving strategy with respect to dimensional analysis problems.

In addition to addressing the effects of the software, the researchers looked at the effects of all curriculum used in the teaching of dimensional analysis, including textbooks, websites, teacher perspectives, etc. The researcher evaluated the current textbook along with three other textbooks adopted by other counties in the State of Tennessee. The researcher also evaluated websites that students and teachers used as supplemental material to enhance learning. The researcher's main goal was to obtain a holistic view of all of the elements that can help or hinder a student's understanding of dimensional analysis.

Enhancing Curriculum and Instruction with Educational Technology

"With recent advances in educational technology, teachers now have a multitude of tools to assist and enhance student learning and motivation" (Mendicino, Razzaq, & Heffernan, 2009, p. 331). Educational technology enables one to capture a student's understanding of content and problem-solving processes in much greater detail (Linn, et al., 2004). "New technologies enable us to track learning over minutes or seconds as learners experiment with models or explore examples and explain their thinking" (Linn, et al., 2004, p. 348). This information can help science education researchers connect these online experiences to make sense of student's problem-solving strategies. Educational technology provides students and teachers with new avenues to explore learning that cannot always be achieved via traditional methods, such as using paper worksheets or assigning problems from the textbook. Today's students are more likely to engage in a variety of content through technological mediums. Thus, by integrating supplemental use of software to help reinforce or introduce topics taught in a traditional fashion, a perfect marriage between the old and new can be achieved.

Conversionoes Alignment with Dimensional Analysis Literature

According to the literature on effective ways of teaching dimensional analysis there are many strategies that could be implemented in this research to enhance student learning of dimensional analysis. The researcher focused on three key area: helping students understand dimensional analysis as a problem solving process (McClure, 1995; Arons, 1990; Cohen et al., 2000; Nurrenbern & Robinson, 2001; Oliver-Hoyo, 2003; Gabel, 199), helping students better understand the relationship between conversion factors (McClure, 1995; Canagaratna, 1987; Robinson, 2003; Nurrenbern & Robinson, 1998; Lyle & Robinson, 2001; Cook & Cook, 2005), and helping students visualize units and understand what the numbers represent (TMW Media Group, 2004a).

The software addressed the first area of helping students understand dimensional analysis as a problem solving process by creating the Hints video tutorial on dimensional analysis problem solving strategies (Appendix AB). This video tutorial was created after the researcher analyzed general chemistry textbooks and focused on providing students a seven-step strategy of solving problems:

1. Read and understand the problem/question
    a. What are you asked to do?
    b. What type of unit of measure is being used?
    c. What information is given?
2. Understand and visualize the units that are used in the problem
    a. Is the given unit Larger or Smaller than the final unit?
    b. Should the final answer be a Larger or Smaller number?
3. Write a mathematical express of the problem
4. Use your knowledge to figure out what conversion factor(s) will help you solve the problem
5. Map out your strategy to solve the problem and set up your conversion factors accordingly

6. Set up your solution and do the arithmetic
7. Check your final answer to see if it is reasonable
    a. Does it answer the initial question?
    b. Does the answer pass the Larger or Smaller test?
    c. Is the final answer in significant figures?
    d. Is the final answer in scientific notation?
    e. Does the answer have the proper units?

In addition to providing this seven-step plan the video walks students through an example that they can solve along with the video. The tutorial also provides students with additional strategies that they can apply when solving problems which address some of the other major areas of effective instruction of dimensional analysis; strategies on visualizing units and understanding the relationship between the conversion factors and how this relationship applies to the current problem. Students had ample opportunities to apply these problem solving strategies in an effort to complete level certifications in dimensional analysis problem solving proficiency in the Dimensional Analysis portion of the software.

The next area that was addressed was helping students to better understand the relationship between conversion factors. The researcher created the Conversionoes Game to help students see how units were related and how they linked together. In addition to focusing on the linking relationship between units, the instructor added another level of detail and showed students the relationship between conversion factors and what type of measurement classification they belong. There were three types of Conversionoes Games students could play; length, mass, and volume. As students played the different types of Conversionoes Games they could see what units belonged in each category while they interacted with the different conversion factors and how all of the units within that category were related.

The final area addressed in the Conversionoes curriculum was helping students visualize units and understand what the numbers represent. This area was mainly addressed in the Larger or Smaller portion of the software. Here students were given two units of measure of the same item and were asked to determine which is smaller or larger. Once students made their selection students were able to "see" the numbers and what types of products are measured with that type of unit. This portion of the game provided students with a visual of what types of units feel under a particular category or measurement (e.g. volume) and what types of units fell under that category (e.g. liters, gallons).

In addition to addressing the main areas of effective instruction of dimensional analysis the researcher also included supporting elements to help students successfully provide a correct answer for the dimensional analysis portion of the software. Video tutorials on putting the final answer in significant figures and putting the final answer in scientific notation were also created (Appendix AD and AE, respectively). From the textbook evaluation it was evident that a prerequisite to dimensional analysis problem solving was mastery of significant figures and scientific notation and being able to apply those skills in determining a final answer. The researcher provided detailed instructions on how to successfully apply these skills and used animation where applicable to show students how to perform certain elements such as counting significant figures.

It was observed by the researcher and mentioned by the participant teachers that many students knew how to set up their problems correctly but had problem using their calculators to produce the proper coefficient/base units and using the functions in their calculators to put their final answer in proper scientific notation. The Hints video on using a scientific or graphing calculator to solve dimensional analysis problems was created to assist students with this problem (Appendix AC). In addition to teaching students which functions on their respective calculators should be used while calculating their final answer the researcher also reviewed the strategies students should use in solving a dimensional analysis problem. The curriculum created for the hints section of the Conversionoes software was designed to reinforce material taught by the participant teachers as well as provided a different vehicle for students who could not grasp the concepts in a traditional setting to learn the material as well. Students had very favorable comments about the hints section that is best summarized in the following quote: “I didn't understand it [dimensional analysis] very well but I do now after watching the video.”

Limitations of the Study

This research was an exploratory study with limited generalizability due to the small sample size. The case study sample contained 12 students (six from each class) from a class of at least 18 students from the treatment group that consisted of six to eight students. One of the major limitations of this study was found in the sample demographics, which were reflected in the small number of participatory schools (just two) and consequently in the limited classroom demographics. In School A, the only races that were represented were White and African-American, while School B’s participants were only White students. Although there were different ethnic groups represented, the undersized number of minorities (six African-American students) limits the transferability strength to this ethnic group in general.

The limitations of the study also included using only public high school general chemistry students, and therefore a limited, non-random sample size. The use of public high school students restricted the generalization of this study’s findings to high school students in general. The interviews also limited the study because students who volunteered may have been more outspoken or atypical of those who did not volunteer. Finally, the research was conducted in the Chattanooga, Tennessee, metropolitan area. This limited the researcher’s ability to transfer the results to areas that do not reflect the demographics of the research area.

Implications for Further Research

There are many opportunities for additional research to confirm the results of this exploratory study, as well as to test the effectiveness of the Conversionoes software to enhance student learning. The study's findings could be tested with larger groups of students representing additional ethnicities, geographic areas, and school types (rural, urban, suburban, private, public, parochial, etc.). Moreover, many students are homeschooled and their parents may not have the depth and breadth of knowledge to truly assist their students with dimensional analysis. Thus, Conversionoes could be used to supplement the available home school curriculum in chemistry education, and research can be done to determine its effectiveness for this demographic as well.

Dimensional analysis is a problem-solving technique used in many academic disciplines and thus there are many opportunities for additional research. Specifically, this study could be expanded to help enhance problem-solving strategies in algebra, physics and biochemistry, areas which also use dimensional analysis as a technique to convert units. The use of the Conversionoes software to enhance learning does not have to be limited to secondary education, but could be used in lower level higher education courses such as general chemistry, physics, engineering, nursing and premedical courses. The effectiveness of the Conversionoes software on students studying in these fields could be analyzed to determine its transferability to various science, engineering, technology and mathematics areas.

Additional research could be done on the tendencies of students' use of the various elements of the Conversionoes software over an extended period of time. The current study only reflected data gathered over a 45 minutes during one class period and only three of the four elements of the software were used due to the time constraints created by the participant teachers. If students were allowed to use the software throughout the semester a tremendous amount of data could be generated to look at a multitude of variables and their impact on student learning.

Further research could be done on the effectiveness of using the Conversionoes Game to engage learners into the concept of dimensional analysis prior to the initial lecture on dimensional analysis. The following questions could be addressed in this study:

1. Who benefits more from the integration of the Conversionoes Game with respect to gender, race, academic standing, etc.?
2. How does the Conversionoes Game help students better understand the linking relationship between units and the category units fall under (i.e. mass, length, volume)?

Another study could be conducted on analyzing the use of the Hints section where the following questions could be addressed:

1. What types of students use the Hints (gender, race, academic standing, virtual school student vs. traditional student, etc.)?
2. How often do they use the Hints?
3. Why do they use the Hints?
4. Are students more likely to use Hints voluntarily are do they have to be prompted? What type of prompt is most effect (oral prompt from instructor or a video/audio prompt for the software when an incorrect answer has been submitted)?
5. Does student use of the Hints increase as the number of incorrect Dimensional Analysis answers increase?
6. Are video Hints more preferable to text/pdf files? If so, why?

Finally, a study could be conducted on how long it takes students to reach Level 1-3 certification. In the current study none of the students were able to reach Level 1 or 2 certification (90% proficiency) during the allotted time. Data could be generated and analyzed on what types of students reached level certification with respect to gender, race, academic standing, etc. What resources students use to help them solve problems (e.g. Hints, other web sources, textbook). There are many aspects of the Conversionoes software that have yet to be explored opening up many doors for continuous research.

Conclusion

The main research question posed in this study was the following: Can supplemental use of interactive proprietary software enhance high school chemistry students' conceptual and visual understanding of dimensional analysis?

A mixed methods study was conducted. The resulting qualitative and quantitative data confirmed that the Conversionoes software enhanced the treatment groups' conceptual and visual understanding of dimensional analysis. The comparisons were conducted at two schools with different demographics, both resulting in similar positive effects on students' overall understanding.

When all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. This was verified by the quantitative data, which indicated a significant difference as well as the descriptive statistics that verified that students from all ethnic groups and gender benefited from software integration. The qualitative data showed that students valued their experiences using the Conversionoes software and were able to enhance their knowledge of all aspects of dimensional analysis.

In an effort to quantify the effects of the software a grading rubric was created that included all of the required elements of a correct answer in Conversionoes, proper use of units, significant figures and scientific notation. The grading rubric weighed those answers that applied all of the skills required in Conversionoes higher than an answer that simple had proper use of units. Students in the treatment group were privy to material (Hints) that specifically addressed all of the elements in the rubric; dimensional analysis problem solving strategies, putting your final answer in proper significant figures, putting your final answer in proper scientific notation and how to use your scientific/graphing calculator to help you solve dimensional analysis problems. An example of how this qualitative data of observing students using the Hints and hearing that student describing during an interview that “prior to watching this video I didn’t understand scientific notation, now I do” was captured in their post-test and their score was reflective of a student that had a comprehensive knowledge of the problem solving process. Moreover, seeing how students in the treatment groups put their final answers on their post-tests in scientific notation and using significant figures—versus students in the control group who neglected to do so—represents another example of the positive effects of using the Conversionoes software, this was also reflected in the Treatment Groups proficiency on the post-test being higher than the Control Group students.

Results of this study could be advantageous for any chemistry teacher facing the dilemma of identifying effective ways to engage students and help them understand the process of solving dimensional analysis problems. Integrating technology like Conversionoes into the general chemistry classroom is one example of how teachers can engage students, as well as present material in a different medium that may be more effective for today’s technology-savvy students.

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APPENDIX A: ASSURE BASED MODEL OF CONVERSIONOES SOFTWARE

Conversionoes©

If they click on any one of the conversionoes they will get to the main page of the software

km km m

m

m m cm

cm

in

Conversionoes©

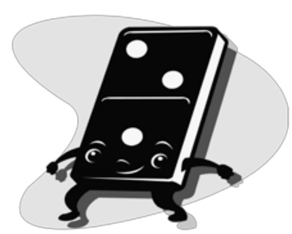
(Homepage)

Students will choose which area they want to start.

Conversion Dominoes

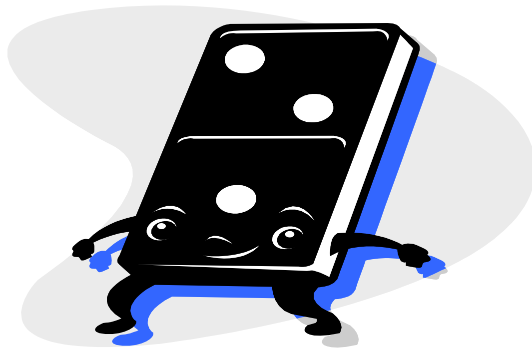
Smaller or Larger

Dimensional Analysis



Hints

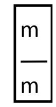
Conversion Dominoes



Conversion Dominoes

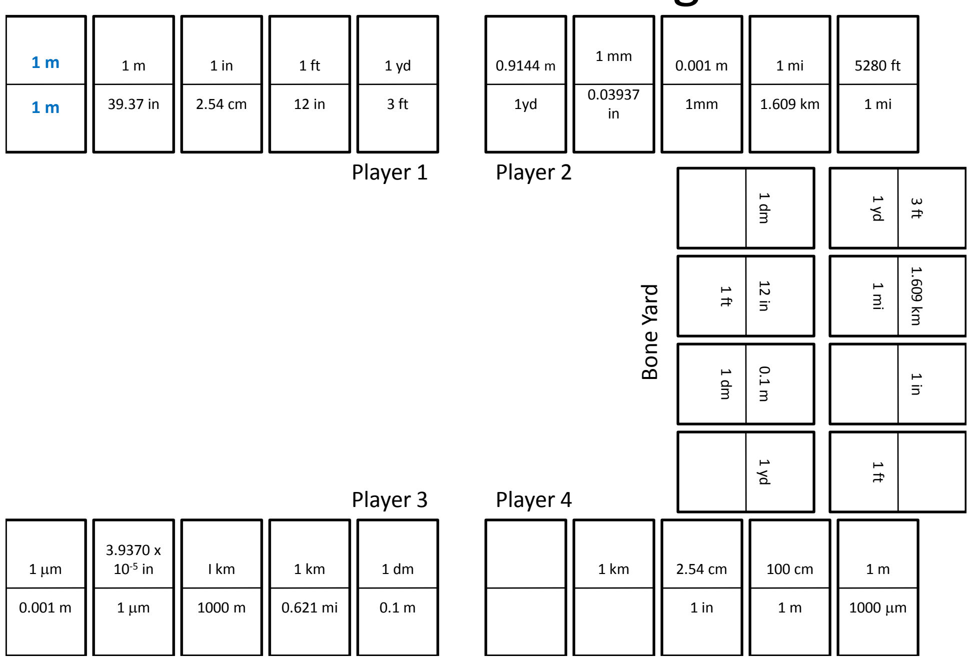
- Demo version of how to play the game.
- Link to the rules (How to Play Conversion Dominoes) will also be provided on this page.

How to Play Conversion Dominoes



1. The player with the highest double places the first domino.
   - Highest doubles will contains the double SI unit for the unit of measure. For example, length m is the SI unit used for the doubles.
2. Play proceeds to the left (clockwise). Each player adds a domino to an open end of the layout, if they can.
3. If a player cannot make a move they must draw a tile from the boneyard.
4. The game ends when one player uses the last domino in their hand, or when no more plays can be made. If all players still have tiles in their hand, but can more no moves can be made, then the game is said to be "blocked".

Conversionoes-Length



Larger or Smaller?

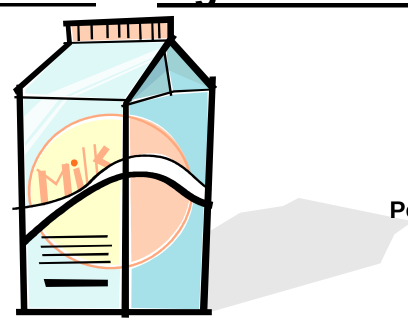
- Rules
- Choose which unit is larger or smaller
- Then see which unit is larger or smaller

Students will answer a series of 10 questions and be given feedback after every answer. A tally of their score will be posted after they complete each problem.

Volume

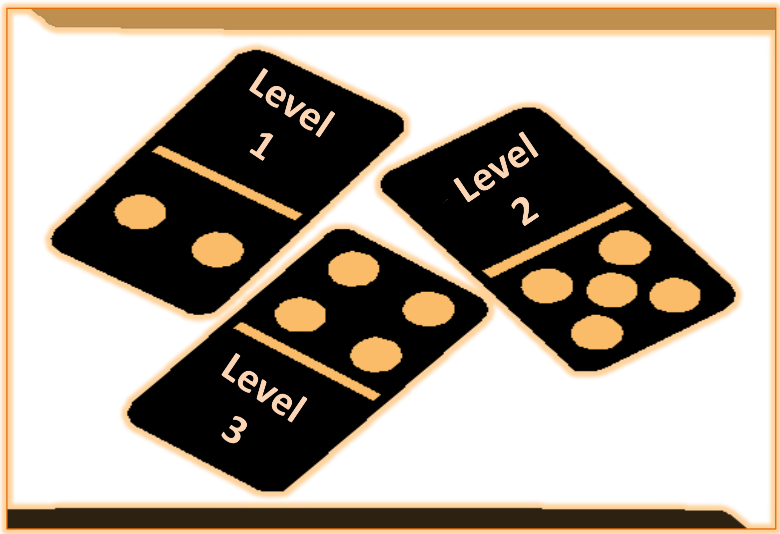
Which is larger?

1 liter of milk or **1 gallon of milk**

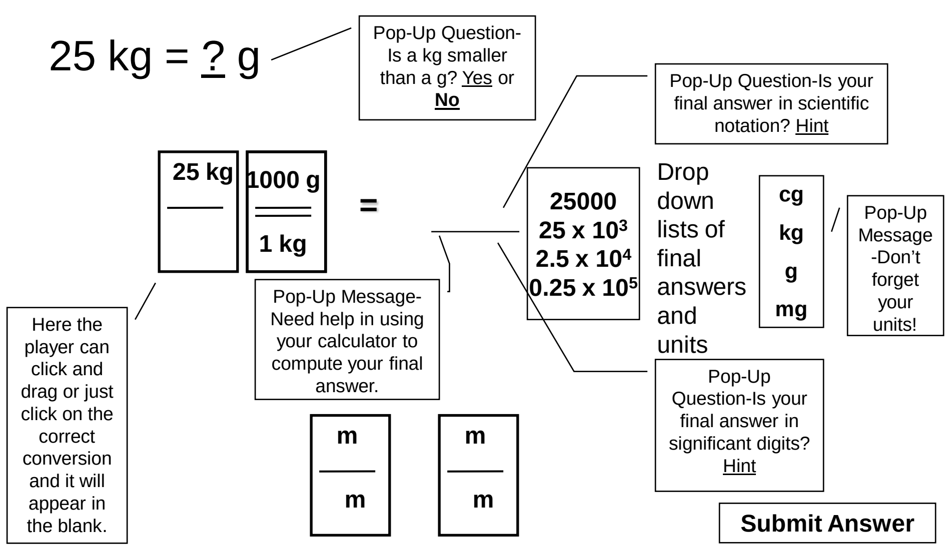


Points 15/100

Dimensional Analysis



Dimensional Analysis



Level 1

Welcome to Level 1. Here you will practice the most simplistic dimensional analysis problems. Feel free to use the Hints while working and before you submit your final answer. Use your Coversionoes® carefully.

Level 1

1. What is 16 millimeters in meters?

$\frac{16\ mm}{\quad} = \frac{?m}{\quad}$

$\frac{16\ \cancel{mm}}{\quad} \; \frac{10^{-3}\ m}{1\ \cancel{mm}} = \frac{\quad}{\quad}$

0.16
0.016
2.5×10^{4}
1.6×10^{-3}
1.6×10^{-2}

mm
m
cm
hm

$\frac{10^{-3}\ m}{1\ mm}$ $\frac{1\ mm}{10^{-3}\ m}$ $\frac{10^{3}\ m}{1\ km}$

Conversionoes©

presents

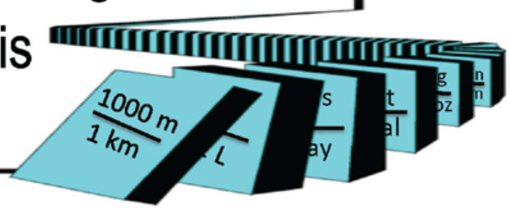
Level 1 Certification

to

____

For

Having a proficiency of 90% or higher in level one dimensional analysis problem solving.



Jennifer T. Pinder Ellis-Conversionoes CEO

Level 2

Welcome to Level 2. Here you will practice the more difficult dimensional analysis problems. Feel free to use the Hints while working and before you submit your final answer. Use your Coversionoes® carefully.

Level 2

4. You and your mother are preparing dessert for Thanksgiving. Your pound cake recipe calls for 2 ½ cups of sugar. You look for the 1 cup and ½ cup measuring cups but they are currently being used by your mother. You notice that there is only a teaspoon available. How many teaspoons of sugar will you need for you cake?

$$\frac{2.5\text{ cups}}{} = \frac{\textbf{?tsp}}{}$$

$$\frac{2.5\text{ }\cancel{\text{cup}}}{} \quad \frac{16\text{ }\cancel{\text{tbsp}}}{1\text{ }\cancel{\text{cup}}} \quad \frac{3\text{ tsp}}{1\text{ }\cancel{\text{tbsp}}} = \frac{}{}$$

<u>120</u>
1.2 x 10^{-2}
1.2 x 10^{-3}
1.2 x 10^{3}
1.2 x 10^{4}

tbsp
<u>tsp</u>
cup
qt

$$\frac{16\text{ tbsp}}{1\text{ cup}} \quad \frac{1\text{ cup}}{16\text{ tbsp}} \quad \frac{2\text{ tbsp}}{1\text{ oz}} \quad \frac{1\text{ tbsp}}{3\text{ tsp}} \quad \frac{3\text{ tsp}}{1\text{ tbsp}}$$

Conversionoes©

presents

Level 2 Certification

to

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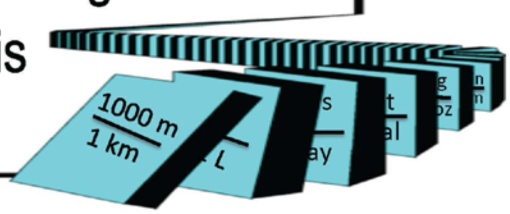
For

Having a proficiency of 90% or higher in level two dimensional analysis problem solving.



Jennifer T. Pinder Ellis-Conversionoes CEO

Level 3

Welcome to Level 3. Here you will practice the most difficult dimensional analysis problems. Feel free to use the Hints while working and before you submit your final answer. Use your Coversionoes® carefully.

Level 3

4. An average household uses 200 gallons of water per day. How many liters of water per week does an average household use?

$$\frac{200\text{ gal}}{\text{day}} = \frac{\mathbf{?L}}{\mathbf{week}}$$

$$\frac{200\text{ }\cancel{\text{gal}}}{\cancel{\text{day}}} \quad \frac{4\text{ }\cancel{\text{qt}}}{1\text{ }\cancel{\text{gal}}} \quad \frac{1\text{ L}}{1.05671\text{ }\cancel{\text{qt}}} \quad \frac{7\text{ }\cancel{\text{day}}}{1\text{ week}} = \frac{\quad}{\quad}$$

5.299 x 10^3
<u>5.0 x 10^3</u>
5.3 x 10^3
7.57 x 10^2
8.0 x 10^2

gal/day
<u>L/week</u>
qt/week
gal/week

$$\frac{1\text{ week}}{7\text{ days}} \quad \frac{4\text{ qt}}{1\text{ gal}} \quad \frac{1\text{ L}}{1.05671\text{ qt}} \quad \frac{7\text{ day}}{1\text{ week}} \quad \frac{1\text{ qt}}{0.946\text{ L}} \quad \frac{2\text{ pint}}{1\text{ qt}}$$

Conversionoes©

presents

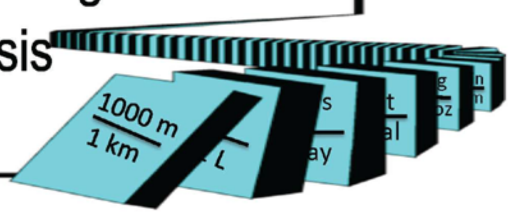
Level 3 Certification

to

____

For

Having a proficiency of 90% or higher in level three dimensional analysis problem solving.



Jennifer T. Pinder Ellis-Conversionoes CEO

Hints

Putting the Final Answer in Significant Figures

- What is the equivalent of 3.8 miles in centimeters?

$$\frac{3.8\ \cancel{mi}}{1} \times \frac{5280\ \cancel{ft}}{1\ \cancel{mi}} \times \frac{12\ \cancel{in}}{1\ \cancel{ft}} \times \frac{2.54\ cm}{1\ \cancel{in}} = \frac{611550.72}{1}\ cm \approx 6.1 \times 10^{5}\ cm$$

3.8 mi	5280 ft / 1 mi	12 in / 1 ft	2.54 cm / 1 in
2 sigi figs	Exact number	Exact number	3 sigi figs

2 Significant Figures

3.8 miles is the lowest measured value

Hints

Using Your Calculator Properly

- If you are going 70 mph, what is your speed in nanometers per second?

$$\frac{70\ miles}{hour} = \frac{?nanometers}{second}$$

$$= \frac{70\ miles}{hour} \times \frac{5280\ ft}{1\ mi} \times \frac{12\ in}{1\ ft} \times \frac{2.54\ cm}{1\ in} \times \frac{10^{7}\ nm}{1\ cm} \times \frac{l\ hr}{60\ min} \times \frac{1min}{60\ sec}$$

$$= \frac{(70 \times 5280 \times 12 \times 2.54 \times 10^{7} \times 1 \times 1)}{(1 \times 1x\ 1x\ 1 \times 60 \times 60)}\ \frac{nm}{s} = \frac{1.1265408 \times 10^{15}\ \frac{nm}{s}}{3600}$$

$$= 3.1 \times 10^{11}\ \frac{nm}{s}$$

Hints

Putting The Final Answer in Scientific Notation

1. Express 4,500,000,000 in scientific notation.

Standard Notation

4500000000.

9 8 7 6 5 4 3 2 1

4.5×10^9

Scientific Notation

Note: The exponent is positive because the number is greater than one.

Hints

DA Problem Solving Strategies

What is 0.264 meters in millimeters?

7. Check your final answer to see if it is reasonable

- Does it answer the initial question?
  - Is the final answer in the appropriate units?
- Does the answer pass the Larger or Smaller test?
  - If initial unit was a Larger unit of measure and the final unit is a smaller unit of measure does the answer make sense? Vice versa?
- Is the final answer in significant figures?
- Is the final answer in scientific notation?

$$\frac{0.264\ \text{m}}{} = \frac{?\text{mm}}{}$$

$$\frac{0.264\ \cancel{\text{m}}}{1} \quad \frac{1\ \text{mm}}{10^{-3}\ \cancel{\text{m}}} = \frac{0.264 \times 1}{1 \times 10^{-3}} = 264\ \text{mm} = 2.64 \times 10^2\ \text{mm}$$

APPENDIX B: SUMMARY OF RESEARCH QUESTIONS, VARIABLES, AND DATA COLLECTION TECHNIQUES

Table 5

Summary of Research Questions, Variables, and Data Collection Techniques

Research Questions	Variables	Instruments Used for Data Collection
Can supplemental use of an interactive proprietary software program enhance high school chemistry students' conceptual and visual understanding of dimensional analysis? QUAL/QUAN		All instruments for the following questions will be used to accept or reject the hypothesis
How is dimensional analysis currently explained in most high school chemistry textbooks, with respect to student's conceptual and visual understanding? QUAL	Pedagogical approaches	Documents, teaching modules provided by textbook company and/or teacher
What supplemental material is typically provided to enhance students' understanding of dimensional analysis? QUAL	Concept curriculum	Documents (websites)
What effect does this material have on student understanding? QUAN	Learning theories	Survey, interviews
What are the textbook-related difficulties high school students have with conceptual understanding of dimensional analysis? QUAL	Concept curriculum	Open-ended interviews, documents
How does the supplemental use of a proprietary interactive software program affect students' conceptual and visual understanding of dimensional analysis? QUAN/QUAL	IV Treatment group vs. Control DV Software assessment data measuring understanding	Interviews, Software assessment data
What effect does the software program have on students' perceptions of the process of dimensional analysis and their ability to grasp the logic behind it? QUAL/QUAN	IV Treatment group vs. Control DV Pre-survey and Post-survey measuring perception V of I Student perception	Survey, observations, interviews
How does the addition of the software change the students' chemical dimensional analysis problem-solving proficiency? QUAN	IV Treatment group vs. Control DV Pre-test and Post-test measuring understanding	Pre-test and posttest

APPENDIX C: SUMMARY OF RESEARCH QUESTIONS, VARIABLES, AND DATA ANALYSIS

Table 6
Summary of Research Questions, Variables, and Data Analysis

Research Questions	Variables	Instruments Used for Data Collection	Data Analysis Techniques
Can supplemental use of an interactive proprietary software program enhance high school chemistry students' conceptual and visual understanding of dimensional analysis? QUAL/QUAN		All instruments for the following questions will be used to accept or reject the hypothesis	Case Study of 12 participants
How is dimensional analysis currently explained in most high school chemistry textbooks, with respect to student's conceptual and visual understanding? QUAL	Pedagogical approaches	Documents, teaching modules provided by textbook company and/or teacher	Constant comparative analysis
What supplemental material is typically provided to enhance students' understanding of dimensional analysis? QUAL	Concept curriculum	Documents (websites)	Constant comparative analysis
What effect does this material have on student understanding? QUAN	Learning theories	Survey, interviews	Constant comparative analysis, transcriptions, looking for emergent themes, quantitizing themes, and an independent t-test of each survey statement
What are the textbook-related difficulties high school students have with conceptual understanding of dimensional analysis? QUAL	Concept curriculum	Open-ended interviews, documents	Transcriptions, looking for emergent themes, quantitizing themes, and constant comparative analysis
How does the supplemental use of a proprietary interactive software program affect students' conceptual and visual understanding of dimensional analysis? QUAN/QUAL	IV Treatment group vs. Control DV Pre and Post test measuring understanding	Interviews, Software assessment data	Raw score comparison for each participant; means, standard deviation and variance will be calculated for each group; interviews transcriptions, looking for emergent themes
What effect does the software program have on students' perceptions of the process of dimensional analysis and their ability to grasp the logic behind it? QUAL/QUAN	IV Treatment group vs. Control DV Pre-test and Post-test measuring understanding V of I Student perception	Survey, observations, interviews	Constant comparative analysis, transcriptions, looking for emergent themes, quantitizing themes, and an independent t-test of each survey statement

How does the addition of the software change the students' chemical dimensional analysis problem-solving proficiency? QUAN	IV Treatment group vs. Control DV Pre-test and Post-test measuring understanding	Pre-test and posttest	Raw score comparison for each participant; means, standard deviation and variance will be calculated for each group; independent t-test will be calculated for comparison between groups and pre-test and post-test scores

APPENDIX D: PARENTAL CONSENT FORM

Parental Permission Form

Project Title: Assessing the Development of High School Chemistry Students' Conceptual and Visual Understanding of Dimensional Analysis via Supplemental use of a Proprietary Interactive Software Program

Performance Site: X High School

Investigators: The following investigator is available for questions,
M-F, 8:00 a.m.-4:30 p.m.
Mrs. Jennifer T. Ellis
Walker Teacher Resource Center
(423) 425-4707

Purpose of the Study: The purpose of this research project is to use software to enhance student learning of dimensional analysis (unit conversions).

Inclusion Criteria: Students who are currently enrolled in general chemistry and whose teachers have referred them for further participation in the study.

Exclusion Criteria: Students who are not currently enrolled in general chemistry or who have not been referred by their teacher, or whose teacher is not participating in the study.

Description of the Study: Over on week, 2-3 days per week, the investigator, posing as a teacher's aide, will observe subjects' interactions with the software, interview referred students, and administer a survey, pretest and posttest.

Benefits: Subjects will have the opportunity to enhance their knowledge of dimensional analysis by using the software. The study may identify ways students can visual units, which in turn will help their conceptual understanding of unit conversions. The benefit to students and the teacher is to integrate technology into the classroom to enhance learning.

Risks: There are no known risks.

Right to Refuse: Participation is voluntary, and a student will become part of the study only if both student and parent agree to the student's participation. At any time, either the subject may withdraw from the study or the subject's parent may withdraw the subject from the study without penalty or loss of any benefit to which they might otherwise be entitled.

Privacy: The school records of participants in this study may be reviewed by investigators. Results of the study may be published, but no names or identifying information will be included for publication. Subject identity will remain confidential unless disclosure is required by law.

Financial Information: There is no cost for participation in the study, nor is there any compensation to the subjects for participation.

Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigator. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I will allow my child to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Parent's Signature:_______________________________ Date:___________________

The parent/guardian has indicated to me that he/she is unable to read. I certify that I have read this consent from to the parent/guardian and explained that by completing the signature line above he/she has given permission for the child to participate in the study.

Signature of Reader:_______________________________ Date:___________________

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
203 B-1 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

APPENDIX E: STUDENT CONSENT FORM

Student Assent Form

I,________________________________, agree to be in a study to find ways to help students enhance their learning of dimensional analysis (unit conversions) in general chemistry. I will have to do special school work for the teacher's aide in my classroom and computer lab. One day I will fill out a survey and take a six-question pretest. Another day I will use the software for this study in the computer lab. The final day I will fill out another survey and take a post-test. I have to follow all the classroom rules, even when I am working with the teacher's aide. I know that my pre-test and post-test scores are not included in my final grade for this class and will only be used for the purposes of this research study. I can decide to stop being in the study at any time without getting in trouble.

Student's Signature:____________________________ Age:______ Date:__________________

Witness* __________________________________ Date:__________________

* (N.B. Witness must be present for the assent process, not just the signature by the minor.)

Institutional Review Board
Dr. Robert Mathews, Chair
203 B-1 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

APPENDIX F: TEACHER CONSENT FORM

Consent Form for a Non-Clinical Study

1. Study Title: Assessing the Development of High School Chemistry Students' Conceptual and Visual Understanding of Dimensional Analysis via Supplemental use of a Proprietary Interactive Software Program

2. Performance Site: X High School

3. Investigators: The following investigator is available for questions,
   M-F, 8:00 a.m.-4:30 p.m.
   Mrs. Jennifer T. Ellis
   Walker Teacher Resource Center
   (423) 425-4707

4. Purpose of the Study: The purpose of this research project is to use software to enhance student learning of dimensional analysis (unit conversions).

5. Subject Inclusion: Veteran high school teachers currently teaching general chemistry.

6. Number of subjects: 2

7. Study Procedures: The study will be conducted in two phases. In the first phase, student subjects will spend approximately 15 minutes completing a survey and a six-question pre-test. The survey will focus on student's perception of dimensional analysis and the pre-test will cover problems students will encounter while using the software. In the second phase, subjects will spend approximately 45 minutes using the software and 15 minutes completing a post-test and a survey.

8. Benefits: Subjects will be given a gift certificate to participate in the study. Additionally, the study may yield valuable information about enhancing student conceptual and visual understanding of dimensional analysis.

9. Risks: There are no known risks.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. Subject identity will remain confidential unless disclosure is required by law.

12. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board,(225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature:______________________________ Date:__________________

Institutional Review Board
Dr. Robert Mathews, Chair
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APPENDIX G: HUMAN SUBJECT RESEARCH COURSE CERTIFICATION

Human Participant Protections Education for Research Teams

Page 1 of 2

National Cancer Institute

U.S. National Institutes of Health | www.cancer.gov

Search GO

NCI Home | Cancer Topics | Clinical Trials | Cancer Statistics | Research & Funding | News | About NCI

Human Participant Protections Education for Research Teams

Completion Certificate

This is to certify that

Jennifer Pinder

has completed the **Human Participants Protection Education for Research Teams** online course, sponsored by the National Institutes of Health (NIH), on 03/16/2006.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

National Institutes of Health

3/16/2006 3:09:07 PM s

APPENDIX H: IRB ACCEPTANCE EMAIL

IRB application Inbox | X

Matt B Edwards to Jennifer show details Feb 27 Reply

Jennifer,

Your project titled "Assessing the Development of High School Chemistry Students' Conceptual and Visual Understanding of Dimensional Analysis via Supplemental use of a Proprietary Interactive Software Program" has been approved. We will need your certificate of completion of the Human Subjects Training Course. The course can be taken online: http://phrp.nihtraining.com/users/login.php

Please send the certificate via email, or campus mail to 130 David Boyd Hall. Please contact the IRB office if you have any questions.

Sincerely,

Matt Edwards

Matthew B. Edwards
Coordinator, Faculty Development
LSU Office of Research and Economic Development
& Institutional Review Board
130 David Boyd Hall
Baton Rouge, LA 70803
Phone: 225-578-8692

APPENDIX I: PRE-TEST AND ANSWER GUIDE

1. Convert 16 millimeters to it equivalent in meters.

2. Your friend invites you to a Lord of the Rings movie marathon which should last approximately 13 hours. How long will you spend watching these movies in minutes?

3. How many liters are 630 gallons of juice?

4. You downloaded a recipe from the Internet for sugar cookies and noticed that all measurements are done in the metric system. How many cups of flour will you need to meet the equivalent of 908 grams?

5. The recommended adult dosage of an over-the-counter pain reliever is 5 mg/kg of body mass. Calculate the dosage in milligram for a 175 pound person.

6. A football field is exactly 100 yards long, what is its length in inches?

PreTest

1) $\frac{16\ \cancel{mm}}{} \Big| \frac{1\ meter}{1000\ \cancel{mm}} = 0.016\ meters = 1.6 \times 10^{-2}\ meters$

2) $\frac{13\ \cancel{hrs}}{} \Big| \frac{60\ min}{1\ \cancel{hr}} = 780\ min = 7.80 \times 10^{2}\ minutes$

3) $\frac{630\ \cancel{gal}}{} \Big| \frac{4\ \cancel{qt}}{1\ \cancel{gal}} \Big| \frac{1\ Liter}{1.057\ \cancel{qt}} = 2381.4 = 2.38 \times 10^{3}\ Liters$

4) $\frac{908\ \cancel{g}}{} \Big| \frac{16\ \cancel{oz}}{454\ \cancel{g}} \Big| \frac{1\ cup}{8\ \cancel{oz}} = 4.00\ cups$

5) $\frac{5\ mg}{1\ kg} \Big| \frac{1\ \cancel{kg}}{1000\ g} \Big| \frac{454\ g}{1\ \cancel{lb}} \Big| \frac{175\ \cancel{lb}}{} = 397.25$
$= 4.0 \times 10^{2}\ mg$

6) $\frac{100\ \cancel{yds}}{} \Big| \frac{36\ in}{1\ yd} = 3.6 \times 10^{3}\ inches$

APPENDIX J: POST-TEST AND ANSWER GUIDE

1. Express 5 megagrams to its equivalent in grams.

2. The distance walking around the average high school three times is 0.75 miles. Convert that distance into feet?

3. Shaquille O'Neal's basketball sneaker is 37 inches long. How long is his sneaker in millimeters?

4. The mass of a gemstone is measured in carats where 1 carat equals 0.215 grams. If the annual worldwide production of aquamarine is 6.5 million carats, how many kilograms does this represent?

5. How many miles could you drive for $20 if the gas mileage of your car is 18 km/liter of gas and the price is $2.97/gallon?

6. Dry sand has a density of 1.5 g/cm^3. A child's sandbox measuring 6.0 ft by 5.0 ft is filled with sand to a depth of 8.0 inches. What is the mass of sand in kilograms?

Post Test

1) $\frac{5\ \cancel{Mg}}{} \Big| \frac{1000 g}{1\ \cancel{Mg}} = 5 \times 10^3\ g$

2) $\frac{0.75\ \cancel{mi}}{} \Big| \frac{5280\ ft}{1\ \cancel{mile}} = 3960\ ft = 4.0 \times 10^3\ ft$

3) $\frac{37\ \cancel{in}}{} \Big| \frac{2.54\ \cancel{cm}}{\cancel{in}} \Big| \frac{10\ mm}{1\ \cancel{cm}} = 939.8 = 9.4 \times 10^2\ mm$

4) $\frac{6.5 \times 10^6\ carats}{} \Big| \frac{0.215 g}{1\ carat} \Big| \frac{1\ kg}{1000 g} = 1397.5 = 1.4 \times 10^3\ kg$

5) $\frac{\$20}{} \Big| \frac{1\ gal}{\$2.97} \Big| \frac{4\ qt}{1\ gal} \Big| \frac{1\ L}{1.057\ \cancel{qt}} \Big| \frac{18\ \cancel{km}}{L} \Big| \frac{1\ mile}{1.61\ \cancel{km}}$

$= 2.8 \times 10^2$ miles

6) $\left[\frac{6.0\ ft}{} \Big| \frac{12\ in}{ft}\right] \times \left[\frac{5.0\ ft}{} \Big| \frac{12\ in}{ft}\right] \times (8.0\ in) \times \left(\frac{2.54\ cm}{1\ in}\right)^3 \times \frac{1.5 g}{1\ cm^3}$

$\times \frac{1\ kg}{1000 g}$

$= 8.5 \times 10^2$ kgrams of sand

APPENDIX K: OBSERVATION FORM

OPTIC-Modified - Observation Protocol for
Technology Integration in the Classroom

Class Demographics:
AA___ W__ AS___ H____ O __

I. Setting and Circumstances:

Observation Length: Start Time ____ End time _____ minutes

Site (check): __Computer lab __Classroom __Other Inside: _______________________
__Outside the building: what setting? ________________________________

Ratio of Students to Station or Device: __1 to 1 __2-5 to 1 __6-9 to 1 __10 to 1 or more

In each category below, check as many as apply during the time of the observation.

Activity: __Individual __Small group __Whole class
__Student Presentation __Teacher Presentation

Choice: The specific uses of technology in this session were
__required of all students __required of some students __unrestricted

Curricular area(s) addressed: __Math __Science __Language Arts __Social Studies
__Foreign Language __Other_____________________

Primary nature of student activity: __Passive and receiving __Producing and creating

Technologies in use: __Computer __Internet __E-mail __Hand held __Camera
__One-way video __Two-way Interactive video __CD Other _______________

Software in use by class during the observation: (Will not total 100%)
__Drill and practice ___% students using
__Simulation or game ___ __Problem solving
___ __Internet browser ___
__Hints/Tutorials ___
__Other:________________

Student objectives for this time period:
__Learn content-related skills, facts or concepts __Develop a project
__Practice or reinforce a skill or concept __Learn a research skill
__Communicate with resource person or peer __Testing or assessment
__Learn a software or application skill (note): ____
__Other (note): ____

Student goals addressed this time period:
__ be a discriminating and technically proficient technology user
__ seek, analyze and evaluate information using technology
__ conduct problem solving and/or decision making activities using technology
__ review content using the Hints

II. Integration Observation Rubric: For each row, place a mark in the bracket in the box best representing the situation you observe. Columns 4 and 2 are provided as intermediate points for your convenience. A mark in column N/A means the item is not applicable in this situation. Use of N/A in any one observation is not a sign of deficiency.

5	4	3	2	1	N/A	Notes
Most students are independently choosing elements within the software appropriate to their learning objectives. [ ]	[ ]	Some students are independently choosing the elements within the software appropriate to their learning objectives. [ ]	[ ]	Students are using only the elements within the software prescribed by the teacher for meeting learning objectives. [ ]	[ ]	
Students are highly involved with their teacher and peers in planning for the use of technology in a unit or lesson. [ ]	[ ]	Students have a moderate role with their teacher and/or peers in planning for the use of technology in a unit or lesson. [ ]	[ ]	Students await and follow teacher directions for what technology to use. [ ]	[ ]	
If students have trouble solving problems, a high degree of collaboration is exhibited. [ ]	[ ]	If students have trouble solving problems, a moderate degree of collaboration is exhibited. [ ]	[ ]	If students have trouble solving problems, few students display collaboration. [ ]	[ ]	
When using technology, most students act ethically and in accordance with the district acceptable use policy. [ ]	[ ]	When using technology, some students are not acting in accordance with the district acceptable use policy. [ ]	[ ]	When using technology, few students follow the district acceptable use policy; many violations are apparent. [ ]	[ ]	
Most students exhibit skill in the effective use of the software. [ ]	[ ]	Some students exhibit skill in the effective use of the software. [ ]	[ ]	Students generally exhibit a low level of skill in their use of the software. [ ]	[ ]	
In using technology, most students are focused on the intended curricular objectives. [ ]	[ ]	In using technology, some students are focused on the intended curricular objectives. [ ]	[ ]	In using technology, few students are focused on the intended curricular objectives. [ ]	[ ]	
Most specific technology skills are embedded and learned in the context of core curriculum lesson objective. [ ]	[ ]	Some specific technology skills are practiced in the process of achieving core curriculum objectives. [ ]	[ ]	Specific technology skills are taught and practiced as sep-arate lessons, and later applied to core objectives. [ ]	[ ]	
Problem solving and higher order thinking is evident in most students' activities. [ ]	[ ]	Problem solving and higher order thinking is evident in about half the class. [ ]	[ ]	Most students exhibit little creativity, only responding to software prompts. [ ]	[ ]	
Most students are highly engaged in the use of software. [ ]	[ ]	Some students are highly engaged in the use of software and others are not. [ ]	[ ]	Few students are highly engaged in the software activity. [ ]	[ ]	
Student use of technology is based on their cognitive abilities and physical needs. [ ]	[ ]	Student use of technology is directed at one of the needs areas. [ ]	[ ]	Student use of technology is directed at neither area. [ ]	[ ]	
Most technology uses represent learning activities that could not otherwise be easily done. [ ]	[ ]	Some technology uses support learning activities that could not be done without it. [ ]	[ ]	Most of the learning activities might be done as well or better without technology. [ ]	[ ]	

APPENDIX L: STUDENT INTERVIEW

PreTreatment Interview

1. What subjects do you enjoy studying in school?
2. What do you want to do when you finish high school?
3. What is dimensional analysis?
    a. Which is smaller 1 cup of brown rice or 1 Tablespoon of Brown Rice

    b. Which is larger 5 ounces of soy sauce or ¾ cups of soy sauce?

c. Can you convert this problem?
    1. There are 2.5 days to a normal weekend. How many hours does that include?
    2. How many micrometers are in 0.026 centimeters?
    i. What steps do you use when you solve these problems?
    ii. Why did you use that conversion factor there?

Post Treatment Interview

1. How often do you use a computer?
2. How often do you use a computer in your Chemistry class?
3. Did you find the dimensional analysis software helpful? Is how? If not why not?
4. Did you use the hints offered in the software? If so which ones? If not, why not?
5. Do you think you have a better understanding of dimensional analysis? Why or why not?
    a. Which is smaller 5 lb bag of flour or a 32 ounce page of flour?

b. Which is larger 141 grams of cooking spray or 8 ounces of cooking spray?

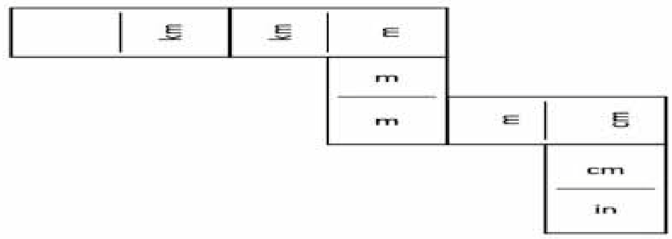
c. Can you convert this problem?

1. What is 6.05 x 10^3 cubic centimeters in liters?
2. A beaker contains 588 mL of water. What is the volume in qt?
    i. What steps did you use to solve these problems?
    ii. Why did you use that conversion factor there?

APPENDIX M: STUDENT PRESURVEY

If you prefer you may take this survey online:
http://www.mrsellis.speedsurvey.com

Conversionoes©



Please help us serve you better by taking a few moments to fill out this survey form. The results will be returned to us automatically via the web.

General Chemistry is one of my favorite classes I am taking this semester.

○ Strongly Disagree ○ Disagree ○ Somewhat ○ Agree ○ Strongly Agree

I am doing well in my General Chemistry class.

○ Strongly Disagree ○ Disagree ○ Somewhat ○ Agree ○ Strongly Agree

Presently I understand the scientific concept of dimensional analysis (unit conversions).

○ Strongly Disagree ○ Disagree ○ Somewhat ○ Agree ○ Strongly Agree

Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook or any handout/worksheet.

○ Strongly Disagree ○ Disagree ○ Somewhat ○ Agree ○ Strongly Agree

Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis problem.

○ Strongly Disagree ○ Disagree ○ Somewhat ○ Agree ○ Strongly Agree

Turn Page Over

If you prefer you may take this survey online:
http://www.mrsellis.speedsurvey.com

I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

Presently I understand the relationship between conversion factors and how to use them to solve various problems.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

Before I determine (circle) my final answer of a dimensional analysis problem, I double check my answer to see if it makes sense.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

While working on my homework if I do not understand a concept I'll search the Internet for tutorials or some form of help.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

What is your gender?

- Male
- Female

Thank you for taking the time to fill out this survey. If you need to contact us - you can click on the following email **jpinde1@tigers.lsu.edu.**

Submit Form | Reset Form

APPENDIX N: STUDENT POSTSURVEY

http://mrsellispost.speedsurvey.com

Conversionoes Post-Survey

I plan to pursue a career in science, technology or engineering when I graduate high school.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

I have used computer software and/or chemistry related websites in chemistry class this semester.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

Presently I understand the scientific concept of dimensional analysis (unit conversions).

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

I found the Conversionoes (dimensional analysis) software helped enhance my understanding of dimensional analysis (unit conversions).

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree
- N/A

What did you find helpful about the software?

Which section(s) of the software did you use?

- [ ] Larger or Smaller
- [ ] Dimensional Analysis
- [ ] Hints
- [ ] None

The larger or smaller portion of the Conversionoes software helped me visualize and understand units.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree
- N/A

Before I submitted my final answer when solving dimensional analysis (unit conversions) problems (either using the software or the worksheet activity), I double checked my answers to see if they made sense.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

I used the hints section of the software or asked a group member when I needed help with a problem.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree

I found the hints section helpful.

- Strongly Disagree
- Disagree
- Somewhat
- Agree
- Strongly Agree
- N/A

Which hints did you use?

- [ ] Putting the final answer in significant figures
- [ ] Putting the final answer in scientific notation
- [ ] Using your calculator (scientific or graphing) to help solve dimensional analysis problems
- [ ] Dimensional analysis problem solving strategies
- [ ] None

To improve the Conversionoes software I would change the following:

What is your gender?

- Male
- Female

Thank you for taking the time to fill out this survey. If you need to contact us - you can click on the following email **jpinde1@tigers.lsu.edu.**

APPENDIX O: TEACHER INTERVIEW

1. How long have you taught General Chemistry?

2. How do you normally introduce the concept of dimensional analysis?

3. How well do you think your students grasp the concept of dimensional analysis?
    a. How long does it take most students?
    b. What normally happens to those that do not grasp the concept in the allotted time?

4. Do you think students understand the relationship between conversion facts and how they should be used to solve various problems?

5. Do you think your students have a good perception of size when you introduce a new unit of measure? For example, would they be able to determine which is smaller a centimeter or a yard?

6. How heavily do your rely on your current textbook in your initial presentation of dimensional analysis?
    a. Do you use it to supplement your lecture?
        i. If so, how?
        ii. If not, why not?

7. Do you feel your current textbook is a sufficient resource with respect to dimensional analysis?
    a. Do you feel the supplemental material (i.e. worksheets) provided by the textbook company is sufficient in helping your students better understand dimensional analysis?

8. What supplemental materials do you use to help students grasp the concept of dimensional analysis?

9. Do you currently integrate technology (e.g. computer-based tutorials) to help students' grasps concepts of dimensional analysis or any other major concept in general chemistry?

10. Do you reference websites that should use if they have trouble with their homework? If so which sites do you recommend?

11. Do you use any images to help students grasp certain elements of dimensional analysis such as size? If so what type of images do you use?

12. Do you view dimensional analysis as a problem solving strategy? If so, what steps do you teach? If not, why not?

APPENDIX P: TEXTBOOK EVALUATION FORM

Book Title:

Author (s):

Publisher:

Year: **Edition:**

Criteria	Ranking 0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	Comments
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.					
Writing Style Writing is descriptive and thought-provoking, and fosters visualization, sparking the reader's imagination on many levels. Vocabulary consists of words that are both familiar and challenging, and words the reader may not know are clearly defined. Main ideas are explicit, no imbedded in the text.					
Headings/subheadings Headings and subheadings support the content and preview what is coming so the reader gets a clear idea about the section and can make predictions and read for purpose-helpful with before-reading activities. Wording is explicit rather than vague or ambiguous.					
Captions and labels Captions and labels are accurate and informative, and supplement the text or main ideas in that part of the book.					
Topic sentences and sections/chapter previews These communicate what is being discussed/developed in the paragraph or section/chapter; allow the reader to establish, identify, and absorb main ideas; and provide helpful information for before reading activities.					
Section/Chapter Summaries Key ideas and main points supporting the topic discussed in the section/chapter are clear and accurately restated.					

Extension Activities Includes relevant activities offering sufficient practice so that the student can reinforce and retain what has been taught. Activities focus on different ways in which students might continue their study based on various learning styles.					
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.					
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to rather than pages before or after it.					
Graphics are consistently identified with call outs, such as Figure1, Figure 2, etc.					
Maps and charts include keys or legends that explain what the symbols means.					
Each photograph includes a caption that succinctly identifies it and makes a direct connection between it and the text.					
End-of-Section/Chapter Comprehension and Critical-Thinking Questions The questions make connections between the learned content, allow the reader to reflect on main ideas, and extend critical thinking about past and future events. Questions also are multi-leveled, i.e., there are questions that the reader can answer by looking in a specific place in the text, some that require the reader to look for clues in what they have read and combine these with their prior knowledge. The number of questions included provides ample practice for students.					
Recommended Reading Includes works that enable the reader to pursue further information.					
Web Sites Include direct links to pertinent information.					
Total Score					

APPENDIX Q: WEBSITE EVALUATION

Website Title:

Website URL:

Author (s):

	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.					
Responsible Author There is a way to validate the information on the web site. It is clear who is responsible for the content. You can contact the person who has written the information. Biographical information on the author's) is contained as a link somewhere within the web pages. There is a way to email the webmaster to ask specific questions.					
Credentials of the Author The content written by a scientist or another type of professional science educator.					
Student Engagement The content promotes inquiry learning. The content promotes human constructivism. Encourages students to think and reflect. Critical thinking skills are needed to analyze and synthesize information. Students can be evaluated on their knowledge acquisition the web site content using some time of formal assessment that provides feedback to the student. Provides interactive opportunities. Resources are provided to facilitate student development.					
Conceptual Understanding Website starts from student's prior knowledge and builds allow students to solve problems independently using skills taught in other segments of the website.					
Visual Understanding Website allows students to see units to get a better understanding of what units mean in relation to other units. Website provides images to help students grasp the concept of size.					

Tutorials The website provides tutorials on how to solve dimensional analysis problems. Either pdf files or some form of video.					
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.					
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to.					
Graphics enhance learning.					
Drill and Practice The website allows the student to practice dimensional analysis problem solving at various levels of complexity.					
Feedback Students receive instant feedback to help them determine mastery of key concepts.					
Functionality All links within the website work properly.					
Total Score					

APPENDIX R: SUPPLEMENTAL ACTIVITY FOR CONTROL GROUP

Names: ____

____

1. Convert a distance of 9.5 feet to centimeters.

9.5 ft	

2. How many teaspoons are in a liter bottle of Coke? You will need to know that there are 3 teaspoons in a tablespoon, and 2 tablespoons in an ounce.

1.0 liter	

3. One 1.623-oz package of Peaches 'n Cream Quaker Instant Oatmeal contains 27 grams of carbohydrates. If you had 2 packages of instant oatmeal for breakfast every day for two weeks, how many pounds of carbohydrates would you consume?

2 weeks	

4. How long does it take light to reach the earth from the sun? You need to know that the sun is 93 million miles from the earth and light travels at a speed of 3×10^8 m/s (a conversions factor). Express the time as minutes.

$9.3 \cdot 10^7$ mi	

5. How much does 1 gallon of water weigh (in pounds)? 1 g of water has a volume of 1 mL.

what is your known?	

6. Make up your own problem to calculate the amount of money that you would spend on cigarettes if you started smoking in high school and continued until your death. You will need to make some assumptions.

7. Create a few problems that require the use some of the conversion dominoes as well as additional conversion factors that you create using the blank conversion dominoes for you and your group members to solve.

12 inch	1 ft	1 inch	2.54 cm				
1 ft	12 inch	2.54 cm	1 inch				
1 liter	1.057 qt	32 oz	1 qt	3 tsp	1 T	1 oz	2 T
1.057 qt	1 liter	1 qt	32 oz	1 T	3 tsp	2 T	1 oz
7 day	1 week	1 day	2 packages	1 package	27 g carbos	1 lb	454 g
1 week	7 day	2 packages	1 day	27 g carbos	1 package	454 g	1 lb
1 mi	1.61 km	5280 ft	1 mi	1000 m	1 km	454 g	1 lb
1.61 km	1 mi	1 mi	5280 ft	1 km	1000 m	1 lb	454 g
1 hr	60 min	1 min	60 s	1 in	2.54 cm	1 gal	4 qt
60 min	1 hr	60 s	1 min	2.54 cm	1 in	4 qt	1 gal
$3 \cdot 10^8$ m (light)	1 s (light)	1000 mL	1 L	1 L	1.057 qt	1 g (water)	1 mL (water)
1 s (light)	$3 \cdot 10^8$ m (light)	1 L	1000 mL	1.057 qt	1 L	1 mL (water)	1 g (water)

DOMINOES

1) $$\frac{9.5\ \cancel{ft}}{} \left| \frac{12\ \cancel{in}}{1\ \cancel{ft}} \right| \frac{2.54\ cm}{1\ \cancel{in}} = 289.56 = 2.9 \times 10^{2}\ cm$$

2) $$\frac{1.0\ \cancel{L}}{} \left| \frac{1.057\ \cancel{qt}}{1\ \cancel{L}} \right| \frac{32\ \cancel{oz}}{1\ \cancel{qt}} \left| \frac{2\ \cancel{T}}{1\ \cancel{oz}} \right| \frac{3\ tsp}{1\ \cancel{T}} = 202.9 = 2.0 \times 10^{2}\ tsp$$

3) $$\frac{2\ wks}{} \left| \frac{7\ \cancel{days}}{1\ wk} \right| \frac{2\ \cancel{packages}}{1\ \cancel{day}} \left| \frac{27\ \cancel{g}\ carbos}{1\ \cancel{package}} \right| \frac{1\ lb}{454\ \cancel{g}} = 1.665 = 1.7\ lbs$$

4) $$\frac{9.3 \times 10^{7}\ \cancel{miles}}{} \left| \frac{1.61\ \cancel{km}}{1\ \cancel{mile}} \right| \frac{1000\ \cancel{m}}{1\ \cancel{km}} \left| \frac{1\ \cancel{s}}{3 \times 10^{8}\ \cancel{m}} \right| \frac{1\ min}{60\ \cancel{s}} = 8.318 = 8.3\ minutes$$

5) $$\frac{1\ gal}{} \left| \frac{4\ qt}{1\ gal} \right| \frac{1\ L}{1.057\ \cancel{qt}} \left| \frac{1000\ mL}{1\ L} \right| \frac{1\ g}{1\ mL} \left| \frac{1\ lb}{454\ g} \right. = 8.335 = 8.3\ lbs$$

6) Example:
Assumptions: 1) I smoke 1 package/day.
2) I smoke for a total of 54 years.
3) The cost per package is fixed at \$5.50/pack for all 54 years.

$$\frac{54\ years}{} \left| \frac{365\ \cancel{days}}{1\ yr} \right| \frac{1\ package}{1\ \cancel{day}} \left| \frac{\$5.50}{1\ \cancel{package}} \right. = \$108{,}405$$

APPENDIX S: WORKBOOK SUPPLEMENTAL MATERIAL

Name ______________________ Section ________ Date ________

Chapter 5: Basic Review Worksheet

1. Explain the scientific meaning of *uncertainty*?

2. Explain how a *unit* is related to a measurement?

3. Explain the terms *conversion factor* and *equivalence statement*.

4. For each of the following, make the indicated conversion.
   a. 122.4×10^5 to standard scientific notation
   b. 5.993×10^{-4} to ordinary decimal notation

5. For each of the following, make the indicated conversion.
   a. 6.0 pt to liters
   b. 6.0 pt to gallons
   c. 5.91 yd to meters
   d. 62.5 mi to kilometers
   e. 88.5 cm to millimeters

6. Evaluate each of the following mathematical expressions, being sure to express the answer to the correct number of significant figures.
   a. $10.20 + 4.1 + 26.0001 + 2.4$
   b. $(1.091 - 0.991) + 1.2$
   c. $(4.06 + 5.1) (2.032 - 1.02)$
   d. $(67.21) (1.003) (2.4)$

7. Make the indicated temperature conversions.
   a. 541 K to Celsius degrees
   b. 221 °C to kelvins

8. Given the following mass, volume, and density information, calculate the missing quantity.
   a. mass = 121.4 g; volume = 42.4 cm^3; density = ? g/cm^3
   b. mass = 0.721 lb; volume = 241 cm^3; density = ? g/cm^3

Name ______________________________ Section ________ Date _________

Chapter 5: Review Worksheet

1. How does uncertainty enter into measurements? How is uncertainty indicated in scientific measurements?

2. Why must a unit be included with a measurement?

3. Give an everyday example of how you might use dimensional analysis to solve a simple problem.

4. For each of the following, make the indicated conversion.
   a. 0.0004321×10^4 to standard scientific notation
   b. 5.241×10^2 to ordinary decimal notation

5. For each of the following, make the indicated conversion.
   a. 16.0 L to fluid ounces
   b. 5.25 L to gallons
   c. 8.25 m to inches
   d. 4.25 kg to pounds
   e. 4.21 in. to centimeters

6. Evaluate each of the following mathematical expressions, being sure to express the answer to the correct number of significant figures.
   a. $[(7.815 + 2.01)(4.5)]/(1.9001)$
   b. $(1.67 \times 10^{-9})(1.1 \times 10^{-4})$
   c. $(4.02 \times 10^{-4})(2.91 \times 10^{3})/(9.102 \times 10^{-1})$
   d. $(1.04 \times 10^{2} + 2.1 \times 10^{1})/(4.51 \times 10^{3})$
   e. $(1.51 \times 10^{-3})^{2}/(1.074 \times 10^{-7})$
   f. $(1.89 \times 10^{2})/[(7.01 \times 10^{-3})(4.1433 \times 10^{4})]$

7. Make the indicated temperature conversions.
   a. – 50.1°C to Fahrenheit degrees
   b. – 30.7 °F to Celsius degrees

8. Given the following mass, volume, and density information, calculate the missing quantity.
   a. mass = ? g; volume = 124.1 mL; density = 0.821 g/mL
   b. mass = ? g; volume = 4.51 L; density = 1.15 g/cm^3

APPENDIX T: TEXTBOOK EVALUATION-WORLD OF CHEMISTRY

Book Title: World of Chemistry-HCDE Current Textbook

Author (s): Zumdahl, S.S., Zumdahl, S.L., and DeCoste, D.J.

Publisher: McDougal Littell: A Houghton Mifflin Company

Year: 2002 **Edition:**

Chapter 5: Measurements and Calculations

	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Writing Style Writing is descriptive and thought-provoking, and fosters visualization, sparking the reader's imagination on many levels. Vocabulary consists of words that are both familiar and challenging, and words the reader may not know are clearly defined. Main ideas are explicit, no imbedded in the text.				X	
Headings/subheadings Headings and subheadings support the content and preview what is coming so the reader gets a clear idea about the section and can make predictions and read for purpose-helpful with before-reading activities. Wording is explicit rather than vague or ambiguous.			X		
Captions and labels Captions and labels are accurate and informative, and supplement the text or main ideas in that part of the book.				X	
Topic sentences and sections/chapter previews These communicate what is being discussed/developed in the paragraph or section/chapter; allow the reader to establish, identify, and absorb main ideas; and provide helpful information for before reading activities.				X	
Section/Chapter Summaries Key ideas and main points supporting the topic discussed in the section/chapter are clear and accurately restated.	X				

Extension Activities Includes relevant activities offering sufficient practice so that the student can reinforce and retain what has been taught. Activities focus on different ways in which students might continue their study based on various learning styles.		X			Only one extension activity was provided in the textbook.
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.		X			Very few images provided in section and chapter.
Graphic Elements (photographs, illustrations, maps, charts, etc.)					Graphics were minimal and not extremely relevant to the topic. The did not enhance the learning much nor did they help enhance student's ability to see units.
Graphics are located with the text that they refer to rather than pages before or after it.			X		
Graphics are consistently identified with call outs, such as Figure1, Figure 2, etc.			X		
Maps and charts include keys or legends that explain what the symbols means.			X		
Each photograph includes a caption that succinctly identifies it and makes a direct connection between it and the text.			X		
End-of-Section/Chapter Comprehension and Critical-Thinking Questions The questions make connections between the learned content, allow the reader to reflect on main ideas, and extend critical thinking about past and future events. Questions also are multi-leveled, i.e., there are questions that the reader can answer by looking in a specific place in the text, some that require the reader to look for clues in what they have read and combine these with their prior knowledge. The number of questions included provides ample practice for students.			X		There were only 4 problems on DA specifically and a few "critical thinking" problems.
Recommended Reading Includes works that enable the reader to pursue further information.	X				
Web Sites Include direct links to pertinent information.	X				
Total Score		26	57.78%		

Additional Comments: Than the other books but the chapter title is similar to the others. Has DA later in the book. Sees DA as problem solving; section is called Problem Solving and DA.

APPENDIX U: TEXTBOOK EVALUATION-CHEMISTRY: MATTER AND CHANGE

Book Title: Chemistry Matter and Change

Author (s): Dingrando, L., Gregg, K. V., Hainen, N., and Wistrom, C.

Publisher: Glencoe/McGraw-Hill

Year: 2002 **Edition:** N/A

Chapter 2: Data Analysis

Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	Comments
	Ranking				
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Writing Style Writing is descriptive and thought-provoking, and fosters visualization, sparking the reader's imagination on many levels. Vocabulary consists of words that are both familiar and challenging, and words the reader may not know are clearly defined. Main ideas are explicit, no imbedded in the text.				X	
Headings/subheadings Headings and subheadings support the content and preview what is coming so the reader gets a clear idea about the section and can make predictions and read for purpose-helpful with before-reading activities. Wording is explicit rather than vague or ambiguous.				X	
Captions and labels Captions and labels are accurate and informative, and supplement the text or main ideas in that part of the book.				X	
Topic sentences and sections/chapter previews These communicate what is being discussed/developed in the paragraph or section/chapter; allow the reader to establish, identify, and absorb main ideas; and provide helpful information for before reading activities.				X	
Section/Chapter Summaries Key ideas and main points supporting the topic discussed in the section/chapter are clear and accurately restated.				X	

Extension Activities Includes relevant activities offering sufficient practice so that the student can reinforce and retain what has been taught. Activities focus on different ways in which students might continue their study based on various learning styles.				X	There is additional help on DA in the Math Handbook as well as supplemental practice problems both found in the Appendix of the textbook.
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.				X	
Graphic Elements (photographs, illustrations, maps, charts, etc.)					Overall the graphics were done well.
Graphics are located with the text that they refer to rather than pages before or after it.				X	
Graphics are consistently identified with call outs, such as Figure1, Figure 2, etc.				X	
Maps and charts include keys or legends that explain what the symbols means.				X	
Each photograph includes a caption that succinctly identifies it and makes a direct connection between it and the text.				X	
End-of-Section/Chapter Comprehension and Critical-Thinking Questions The questions make connections between the learned content, allow the reader to reflect on main ideas, and extend critical thinking about past and future events. Questions also are multi-leveled, i.e., there are questions that the reader can answer by looking in a specific place in the text, some that require the reader to look for clues in what they have read and combine these with their prior knowledge. The number of questions included provides ample practice for students.			X		More critical thinking questions should have been presented here.
Recommended Reading Includes works that enable the reader to pursue further information.		X			Princeton Review test tips.
Web Sites/Other Ed Tech Tools Include direct links to pertinent information.				X	Textbook includes addition CDRom with interactive resources.
Total Score		42	93.33%		

Additional Comments: Dingrando teaches high school chem. Gregg an assistant professor in division of natural sciences at Ohio Dominican College. Hainen taught chem and physics for 31 years. Winstrom is an associate prof of chem at St. Joseph's College in Rensselar, IN

APPENDIX V: TEXTBOOK EVALUATION-CHEMISTRY

Book Title: Chemistry

Author (s): Wilbraham, A.C., Staley, D.D, Matta, M.S., and Waterman, E.L.

Publisher: Prentice Hall

Year: 2002 **Edition:** N/A

Chapter 4: Problem Solving in Chemistry

	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Writing Style Writing is descriptive and thought-provoking, and fosters visualization, sparking the reader's imagination on many levels. Vocabulary consists of words that are both familiar and challenging, and words the reader may not know are clearly defined. Main ideas are explicit, no imbedded in the text.				X	
Headings/subheadings Headings and subheadings support the content and preview what is coming so the reader gets a clear idea about the section and can make predictions and read for purpose-helpful with before-reading activities. Wording is explicit rather than vague or ambiguous.				X	
Captions and labels Captions and labels are accurate and informative, and supplement the text or main ideas in that part of the book.				X	
Topic sentences and sections/chapter previews These communicate what is being discussed/developed in the paragraph or section/chapter; allow the reader to establish, identify, and absorb main ideas; and provide helpful information for before reading activities.				X	
Section/Chapter Summaries Key ideas and main points supporting the topic discussed in the section/chapter are clear and accurately restated.				X	

Extension Activities Includes relevant activities offering sufficient practice so that the student can reinforce and retain what has been taught. Activities focus on different ways in which students might continue their study based on various learning styles.				X	Animations are provided so students can see measurements. CHEMASAP CDRom also has an interactive tutorial guide on sigi figs. There is a CD ROM for teachers called ResourcePro on problem solving skills.
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.				X	Excellent visual images that help students see what the units mean and the relationship between conversion factors. Really like their use of smaller number larger unit to help students better understand.
Graphic Elements (photographs, illustrations, maps, charts, etc.)					Figures and tables are relate to real world problems to further emphasize that students will use DA after they leave a general chem
Graphics are located with the text that they refer to rather than pages before or after it.				X	
Graphics are consistently identified with call outs, such as Figure1, Figure 2, etc.				X	
Maps and charts include keys or legends that explain what the symbols means.				X	
Each photograph includes a caption that succinctly identifies it and makes a direct connection between it and the text.				X	
End-of-Section/Chapter Comprehension and Critical-Thinking Questions The questions make connections between the learned content, allow the reader to reflect on main ideas, and extend critical thinking about past and future events. Questions also are multi-leveled, i.e., there are questions that the reader can answer by looking in a specific place in the text, some that require the reader to look for clues in what they have read and combine these with their prior knowledge. The number of questions included provides ample practice for students.				X	The book has several opportunities for students to apply DA problem solving skills. The problems vary from Small-scale labs (making accurate measurements and applying mathematics) to having students solve more complex open-ended problems, mini lab on DA. Multiple opportunities for students to apply their skills.
Recommended Reading Includes works that enable the reader to pursue further information.				X	
Web Sites Include direct links to pertinent information.				X	www.phschool.com has interactive quizzes for students to practice
Total Score		45	100.00%		

Additional Comments: First textbook that did not give a bio of the authors in the first few pages of the book. Only book to put DA in the 4th Chapter which is named Problem Solving. Other books put DA with earlier chapters which in this case is Scientific Measurement and includes topics such as the important of measurement, uncertainty in measurements, SI units, density and temperature. Most of the time DA is buried somewhere in between this topics normally after significant figures and/or scientific notation or after density. This book treats DA as a problem solving skill and starts the section on explaining how conversion factors are used in the real world by giving a practical example currency exchanges.

APPENDIX W: TEXTBOOK EVALUATION-MODERN CHEMISTRY

Book Title: Modern Chemistry

Author (s): Davis, Raymond E., Metcalfe, H. C., Williams, J. E., & Castka, J. F.

Publisher: Holt, Rinehart and Winston

Year: 2002 **Edition:** N/A

Chapter 2: Measurements and Calculations

Criteria **Ranking**

Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Writing Style Writing is descriptive and thought-provoking, and fosters visualization, sparking the reader's imagination on many levels. Vocabulary consists of words that are both familiar and challenging, and words the reader may not know are clearly defined. Main ideas are explicit, no imbedded in the text.				X	
Headings/subheadings Headings and subheadings support the content and preview what is coming so the reader gets a clear idea about the section and can make predictions and read for purpose-helpful with before-reading activities. Wording is explicit rather than vague or ambiguous.				X	
Captions and labels Captions and labels are accurate and informative, and supplement the text or main ideas in that part of the book.				X	
Topic sentences and sections/chapter previews These communicate what is being discussed/developed in the paragraph or section/chapter; allow the reader to establish, identify, and absorb main ideas; and provide helpful information for before reading activities.				X	
Section/Chapter Summaries Key ideas and main points supporting the topic discussed in the section/chapter are clear and accurately restated.	X				

Extension Activities Includes relevant activities offering sufficient practice so that the student can reinforce and retain what has been taught. Activities focus on different ways in which students might continue their study based on various learning styles.		X			There are only four conversion factor problems in the back of the textbook. None of the problems have clear real world applications (examples).
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.			X		
Graphic Elements (photographs, illustrations, maps, charts, etc.)					Overall the graphics are done well.
Graphics are located with the text that they refer to rather than pages before or after it.				X	
Graphics are consistently identified with call outs, such as Figure1, Figure 2, etc.				X	
Maps and charts include keys or legends that explain what the symbols means.				X	
Each photograph includes a caption that succinctly identifies it and makes a direct connection between it and the text.				X	
End-of-Section/Chapter Comprehension and Critical-Thinking Questions The questions make connections between the learned content, allow the reader to reflect on main ideas, and extend critical thinking about past and future events. Questions also are multi-leveled, i.e., there are questions that the reader can answer by looking in a specific place in the text, some that require the reader to look for clues in what they have read and combine these with their prior knowledge. The number of questions included provides ample practice for students.			X		The of the chapter problems were lacking. There were only four specific problems on DA. The Alternative Assessment was had great real world application where students were asked to use nutritional facts to make various calculations.
Recommended Reading Includes works that enable the reader to pursue further information.			X		Students are recommend to use the Elements Handbook to look up additional information.
Web Sites Include direct links to pertinent information.		X			Only provided web links for Sigi Figs.
Total Score		34	75.56%		

Additional Comments: Authors
Davis, PhD, Distinguished Teaching Professor in the Depart of Chem and BioChem at Univ of Texas, Austin. Mecalfe, Former Chemistry Teacher and Science Dept Chair. Williams, Former Chem Teacher and Science Dept Chair. Castka, Former Adjunct Associate Prof. Refers to DA as conversion factors.

APPENDIX X: WEBSITE EVALUATION-ALAN'S PAGE

Website Title: Alan's Chemistry Page-Tutorial:Dimensional Analysis

Website URL: http://chemistry.alanearhart.org/Tutorials/DimAnal/

Author (s): Alan D. Earhart (Chemistry instructor at Southeast Community College, Lincoln, NE)

	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Responsible Author There is a way to validate the information on the web site. It is clear who is responsible for the content. You can contact the person who has written the information. Biographical information on the author's) is contained as a link somewhere within the web pages. There is a way to email the webmaster to ask specific questions.				X	
Credentials of the Author The content written by a scientist or another type of professional science educator.		X			
Student Engagement The content promotes inquiry learning. The content promotes human constructivism. Encourages students to think and reflect. Critical thinking skills are needed to analyze and synthesize information. Students can be evaluated on their knowledge acquisition the web site content using some time of formal assessment that provides feedback to the student. Provides interactive opportunities. Resources are provided to facilitate student development.			X		
Conceptual Understanding Website starts from student's prior knowledge and builds allow students to solve problems independently using skills taught in other segments of the website.				X	Does a good job of providing a variety examples of how/where DA is used in the real world.
Visual Understanding Website allows students to see units to get a better understanding of what units mean in relation to other units. Website provides images to help students grasp the concept of size.		X			Only visual images are of units canceling.

Tutorials The website provides tutorials on how to solve dimensional analysis problems. Either pdf files or some form of video.				X	
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.			X		The page layout is ok but very simple.
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to.	X				
Graphics enhance learning.	X				
Drill and Practice The website allows the student to practice dimensional analysis problem solving at various levels of complexity.				X	
Feedback Students receive instant feedback to help them determine mastery of key concepts.				X	Quizzes are available for students to take and are Graded immediately.
Functionality All links within the website work properly.		X			Although all links work some of them do not have a way for you to get back to your previous page other than clicking the Back button. Poor navigation.

Total Score	25	64.10%

Additional Comments: When you clicked on some of the links you had to press the back button to return to the main page. Poor navigation.

APPENDIX Y: WEBSITE EVALUATION-CHEMISTRY TUTORIALS

Website Title: Section 1.4: Dimensional Analysis

Website URL: http://www.wwnorton.com/college/chemistry/gilbert/tutorials/ch1.htm

Author (s): Science Technologies

Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	Comments
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Responsible Author There is a way to validate the information on the web site. It is clear who is responsible for the content. You can contact the person who has written the information. Biographical information on the author's) is contained as a link somewhere within the web pages. There is a way to email the webmaster to ask specific questions.			X		
Credentials of the Author The content written by a scientist or another type of professional science educator.			X		
Student Engagement The content promotes inquiry learning. The content promotes human constructivism. Encourages students to think and reflect. Critical thinking skills are needed to analyze and synthesize information. Students can be evaluated on their knowledge acquisition the web site content using some time of formal assessment that provides feedback to the student. Provides interactive opportunities. Resources are provided to facilitate student development.			X		
Conceptual Understanding Website starts from student's prior knowledge and builds allow students to solve problems independently using skills taught in other segments of the website.				X	
Visual Understanding Website allows students to see units to get a better understanding of what units mean in relation to other units. Website provides images to help students grasp the concept of size.		X			Allowed you to see how to cancel the units.

Tutorials The website provides tutorials on how to solve dimensional analysis problems. Either pdf files or some form of video.				X	
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.			X		
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to.		X			
Graphics enhance learning.		X			
Drill and Practice The website allows the student to practice dimensional analysis problem solving at various levels of complexity.			X		Few problems inbetted within the software.
Feedback Students receive instant feedback to help them determine mastery of key concepts.			X		
Functionality All links within the website work properly.		X			

Total Score 23 58.97%

Additional Comments:
Science Technologies

Principals:
- James Caras, Ph.D.
- Paige Caras
- Barrie Kitto, Ph.D.

Media Creators:
- Ron Berry
- Peat Duggins
- Jarle Lillemoen,Ph.D.
- Jeff Sims
- Nathan Wheeler

Content Leads:
- Brian Arneson, M.S.
- Julie Berwald, Ph.D.
- Jon Harmon
- Anneke Metz, Ph.D.
- Rhonda Raymond, Ph.D.
- Jessica White, M.S.

APPENDIX Z: WEBSITE EVALUATION-DIMENSIONAL ANALYSIS

Website Title: Dimensional Analysis

Website URL: http://www.scribd.com/doc/7868914/Dimensional-Analysis

Author (s): The Port of Long Beach

	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.				X	
Responsible Author There is a way to validate the information on the web site. It is clear who is responsible for the content. You can contact the person who has written the information. Biographical information on the author's) is contained as a link somewhere within the web pages. There is a way to email the webmaster to ask specific questions.			X		It is clear what organization is responsible but not the author of the website.
Credentials of the Author The content written by a scientist or another type of professional science educator.	X				
Student Engagement The content promotes inquiry learning. The content promotes human constructivism. Encourages students to think and reflect. Critical thinking skills are needed to analyze and synthesize information. Students can be evaluated on their knowledge acquisition the web site content using some time of formal assessment that provides feedback to the student. Provides interactive opportunities. Resources are provided to facilitate student development.			X		
Conceptual Understanding Website starts from student's prior knowledge and builds allow students to solve problems independently using skills taught in other segments of the website.			X		
Visual Understanding Website allows students to see units to get a better understanding of what units mean in relation to other units. Website provides images to help students grasp the concept of size.			X		Uses some images (mainly cargo units) to help students understand the relationshop between conversion factors.

Tutorials The website provides tutorials on how to solve dimensional analysis problems. Either pdf files or some form of video.			X		
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.		X			The site is more or less PowerPoint slides that are interactive.
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to.			X		
Graphics enhance learning.			X		
Drill and Practice The website allows the student to practice dimensional analysis problem solving at various levels of complexity.			X		
Feedback Students receive instant feedback to help them determine mastery of key concepts.			X		Students are allowed to check their answers for feedback.
Functionality All links within the website work properly.		X			
Total Score		23	58.97%		

APPENDIX AA: WEBSITE EVALUATION-MATH SKILLS

Website Title: Math Skills Review-Dimensional Analysis

Website URL: http://www.chem.tamu.edu/class/fyp/mathrev/mr-da.html

Author (s): Dr. Wendy Keeney-Kennicutt, Department of Chemistry, Texas A&M University

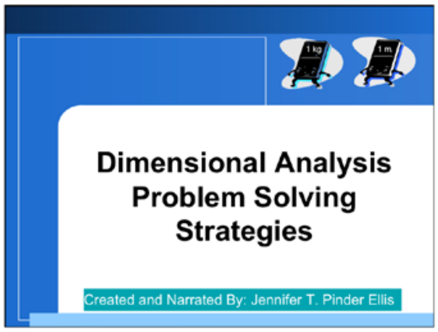
	Ranking				
Criteria	0 No Evidence	1 Little Evidence	2 Moderate Evidence	3 Overwhelm-ing Evidence	**Comments**
Content Accuracy The subject matter is presented either topically or functionally in a logical, organized manner.			X		
Responsible Author There is a way to validate the information on the web site. It is clear who is responsible for the content. You can contact the person who has written the information. Biographical information on the author's) is contained as a link somewhere within the web pages. There is a way to email the webmaster to ask specific questions.			X		
Credentials of the Author The content written by a scientist or another type of professional science educator.		X			Had to research the author's creditials but found that her research area is chemical education.
Student Engagement The content promotes inquiry learning. The content promotes human constructivism. Encourages students to think and reflect. Critical thinking skills are needed to analyze and synthesize information. Students can be evaluated on their knowledge acquisition the web site content using some time of formal assessment that provides feedback to the student. Provides interactive opportunities. Resources are provided to facilitate student development.		X			
Conceptual Understanding Website starts from student's prior knowledge and builds allow students to solve problems independently using skills taught in other segments of the website.			X		
Visual Understanding Website allows students to see units to get a better understanding of what units mean in relation to other units. Website provides images to help students grasp the concept of size.	X				

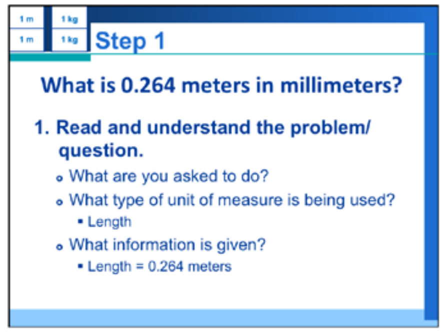
Tutorials The website provides tutorials on how to solve dimensional analysis problems. Either pdf files or some form of video.		X			
Page Layout The text is complemented/supported by graphic elements (illustrations, photographs, maps, charts, etc.) that follow Tufte's principles for graphic design. They do not crowd the page or overwhelm the student with too much textual or visual information.	X				
Graphic Elements (photographs, illustrations, maps, charts, etc.)					
Graphics are located with the text that they refer to.	X				
Graphics enhance learning.	X				
Drill and Practice The website allows the student to practice dimensional analysis problem solving at various levels of complexity.		X			
Feedback Students receive instant feedback to help them determine mastery of key concepts.			X		
Functionality All links within the website work properly.				X	

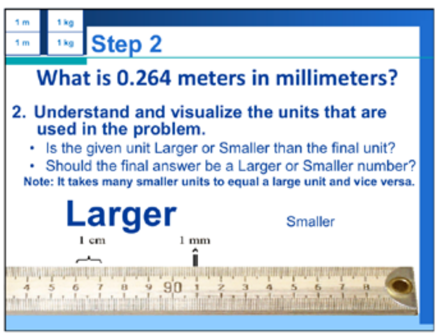
Total Score	15	41.67%

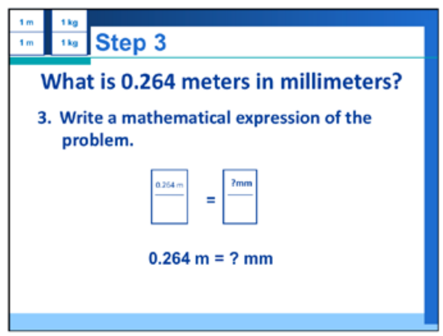
Additional Comments: Senior Lecturer. Associate Director of the First Year Chemistry Program. B. Sc., 1972, Queen's University, Canada. M. Sc., 1974, Queen's University, Canada. Ph. D., 1981, Texas A&M University. Chemical Education. Cooperative learning. Relationship between teaching methods and student learning success.

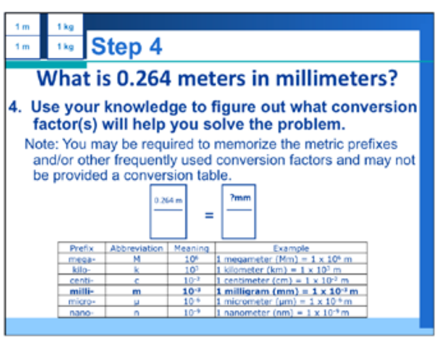
APPENDIX AB: HINTS-PROBLEM SOLVING



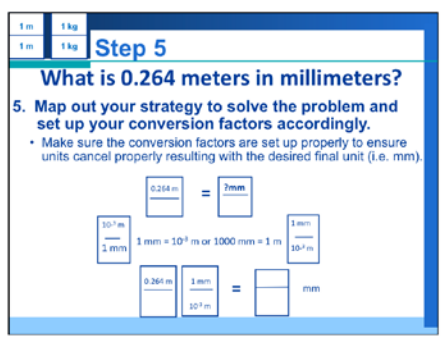








Prefix	Abbreviation	Meaning	Example
mega-	M	10^6	1 megameter (Mm) = 1 x 10^6 m
kilo-	k	10^3	1 kilometer (km) = 1 x 10^3 m
centi-	c	10^{-2}	1 centimeter (cm) = 1 x 10^{-2} m
milli-	**m**	**10^{-3}**	**1 milligram (mm) = 1 x 10^{-3} m**
micro-	µ	10^{-6}	1 micrometer (µm) = 1 x 10^{-6} m
nano-	n	10^{-9}	1 nanometer (nm) = 1 x 10^{-9} m



Step 6

What is 0.264 meters in millimeters?

6. **Set up your solution and do the arithmetic.**
   - Multiply the numerators.
   - Multiply the denominators.
   - Divide the product of the numerators by the product of the denominators.
   - Cross out units where appropriate.
     - You should only have the desired unit left (i.e. mm).

$$\boxed{\frac{0.264\text{ m}}{\ }} = \boxed{\frac{?\text{mm}}{\ }}$$

$$\boxed{\frac{0.264\text{ m}}{1}}\ \boxed{\frac{1\text{ mm}}{10^{-3}\text{ m}}} = \boxed{\frac{0.264 \times 1}{1 \times 10^{-3}}}\ \text{mm}$$

Step 7

What is 0.264 meters in millimeters?

7. **Check your final answer to see if it is reasonable**
   - Does it answer the initial question?
     - Is the final answer in the appropriate units?
   - Does the answer pass the Larger or Smaller test?
     - If initial unit was a Larger unit of measure and the final unit is a smaller unit of measure does the answer make sense? Vice versa?
   - Is the final answer in significant figures?
   - Is the final answer in scientific notation?

$$\boxed{\frac{0.264\text{ m}}{\ }} = \boxed{\frac{?\text{mm}}{\ }}$$

$$\boxed{\frac{0.264\text{ m}}{1}}\ \boxed{\frac{1\text{ mm}}{10^{-3}\text{ m}}} = \boxed{\frac{0.264 \times 1}{1 \times 10^{-3}}} = 264\text{ mm} = 2.64 \times 10^{2}\text{ mm}$$

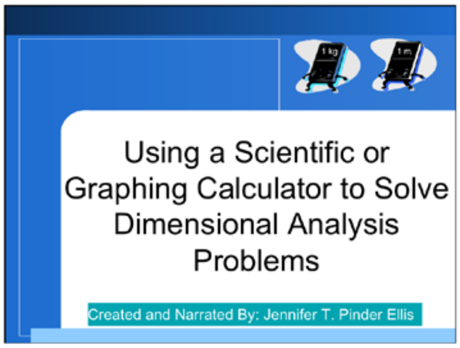
General Dimensional Analysis Problem Solving Suggestions

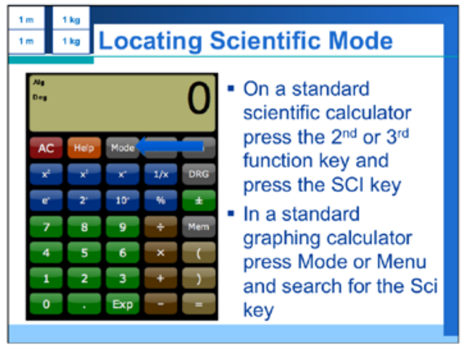
1. **When working any dimensional analysis problem constantly ask yourself questions.**
   - Does this make sense?
     - Solution strategy
     - Final answer
       - Significant figures
       - Scientific notation
   - Do the units cancel?
   - Does the final answer meet my initial expectations?
     - Larger or smaller

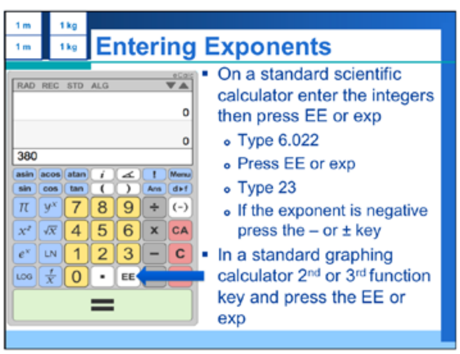
General Dimensional Analysis Problem Solving Suggestions

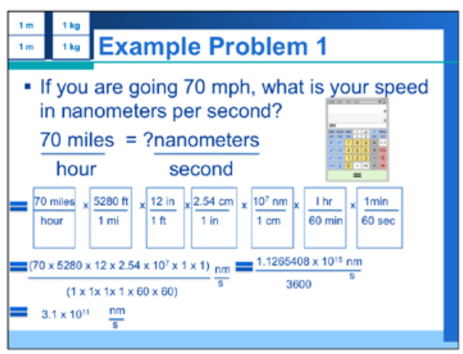
2. **Dimensional analysis is a problem solving strategy and you need to make sure you understand the process.**
   - Why are you using certain conversion factors?
   - How should these conversion factors be used?
   - Try to understand the relationship between the conversion factors and your solution.

APPENDIX AC: HINTS-CALCULATOR









APPENDIX AD: HINTS-SIGNIFICANT FIGURES

6/4/09

Putting the Final Answer in Significant Figures

Created and Narrated By: Jennifer T. Pinder Ellis

General Rules for Deciding the Number of Significant Figures

1. All nonzero digits are significant
   - 3.576 in. has 4 significant figures
   - 9.2 L has 2 significant figures
2. Zeroes sandwiched between nonzero digits are significant
   - 201 kg has 3 significant figures
   - 4.005 cm has 4 significant figures

General Rules for Deciding the Number of Significant Figures

3. Leading zeros to the left of the first nonzero digits are not significant, these zeros are only placeholders.
   - 0.0012 cg has only 2 significant figures
   - 0.0001 °C has only 1 significant figure
4. Trailing zeros that are also to the right of a decimal point in a number are significant.
   - 0.00630 mL has 3 significant figures
   - 0.50 g has 2 significant figures

Counting Significant Figures

Leading Sandwiched Trailing

- 0.000708686060000

1 2 3 4 5 6 7 8 9 10 11 12

12 Significant Figures

General Rounding Rules

1. If the digit to be dropped is greater than 5, the last retained digit is increased by one.
   - 13.7 is rounded to 14
   - 0.0787 is rounded to 0.079
2. If the digit to be dropped is less than 5, the last remaining digit is left as is.
   - 11.4 is rounded to 11
   - 0.0006722 is rounded to 0.000672

General Rounding Rules

3. If the digit to be dropped is 5, and if any digit following it is not zero, the last remaining digit is increased by one.
   - 15.52 is rounded to 16
4. If the digit to be dropped is 5 and is followed only by zeroes, the last remaining digit is increased by one if it is odd, but left as is if even.
   - 10.5 is rounded to 10
   - 15.5 is rounded to 16

The rationale behind this is to avoid bias in rounding, half of the time we round up half of the time we round down.

1

Step 6

What is 0.264 meters in millimeters?

6. **Set up your solution and do the arithmetic.**
   - Multiply the numerators.
   - Multiply the denominators.
   - Divide the product of the numerators by the product of the denominators.
   - Cross out units where appropriate.
     - You should only have the desired unit left (i.e. mm).

$$\frac{0.264\ m}{} = \frac{?mm}{}$$

$$\frac{0.264\ m}{1}\ \frac{1\ mm}{10^{-3}\ m} = \frac{0.264 \times 1}{1 \times 10^{-3}}\ mm$$

Step 7

What is 0.264 meters in millimeters?

7. **Check your final answer to see if it is reasonable**
   - Does it answer the initial question?
     - Is the final answer in the appropriate units?
   - Does the answer pass the Larger or Smaller test?
     - If initial unit was a Larger unit of measure and the final unit is a smaller unit of measure does the answer make sense? Vice versa?
   - Is the final answer in significant figures?
   - Is the final answer in scientific notation?

$$\frac{0.264\ m}{} = \frac{?mm}{}$$

$$\frac{0.264\ m}{1}\ \frac{1\ mm}{10^{-3}\ m} = \frac{0.264 \times 1}{1 \times 10^{-3}} = 264\ mm = 2.64 \times 10^{2}\ mm$$

General Dimensional Analysis Problem Solving Suggestions

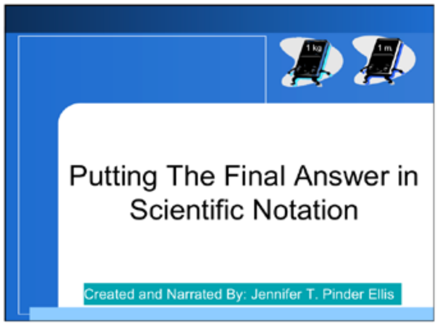
1. **When working any dimensional analysis problem constantly ask yourself questions.**
   - Does this make sense?
     - Solution strategy
     - Final answer
       - Significant figures
       - Scientific notation
   - Do the units cancel?
   - Does the final answer meet my initial expectations?
     - Larger or smaller

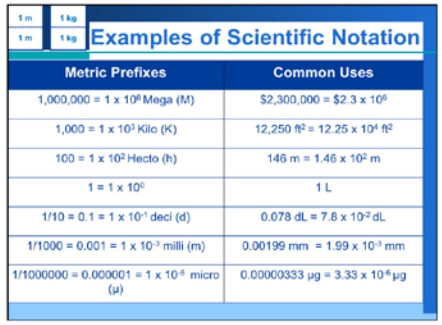
General Dimensional Analysis Problem Solving Suggestions

2. **Dimensional analysis is a problem solving strategy and you need to make sure you understand the process.**
   - Why are you using certain conversion factors?
   - How should these conversion factors be used?
   - Try to understand the relationship between the conversion factors and your solution.

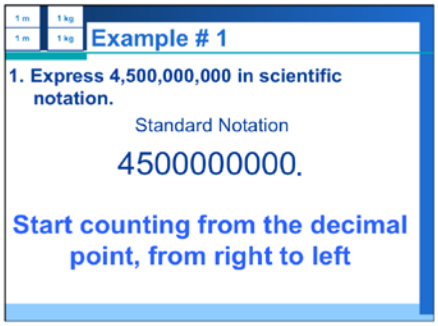
APPENDIX AE: HINTS-SCIENTIFIC NOTATION

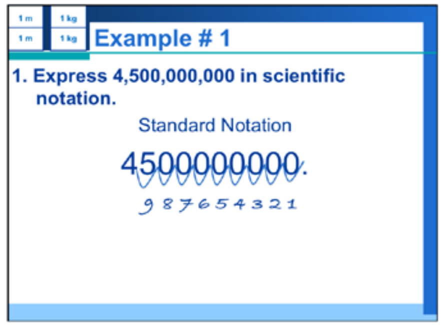
6/4/09

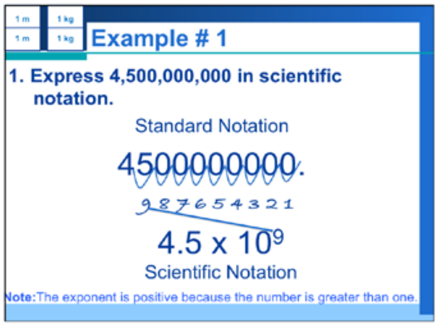


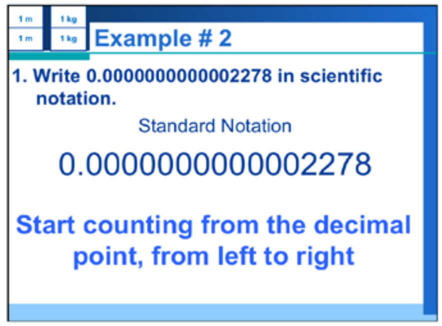


Metric Prefixes	Common Uses
1,000,000 = 1 x 10^6 Mega (M)	\$2,300,000 = \$2.3 x 10^6
1,000 = 1 x 10^3 Kilo (K)	12,250 ft^2 = 12.25 x 10^4 ft^2
100 = 1 x 10^2 Hecto (h)	146 m = 1.46 x 10^2 m
1 = 1 x 10^0	1 L
1/10 = 0.1 = 1 x 10^{-1} deci (d)	0.078 dL = 7.8 x 10^{-2} dL
1/1000 = 0.001 = 1 x 10^{-3} milli (m)	0.00199 mm = 1.99 x 10^{-3} mm
1/1000000 = 0.000001 = 1 x 10^{-6} micro (μ)	0.00000333 μg = 3.33 x 10^{-6} μg









1

Example # 2

1. Write 0.0000000000002278 in scientific notation.

Standard Notation

0.0000000000002278

1 2 3 4 5 6 7 8 9 10 11 12 13

Example # 2

1. Write 0.0000000000002278 in scientific notation.

Standard Notation

0.0000000000002278

1 2 3 4 5 6 7 8 9 10 11 12 13

2.278×10^{-13}

Scientific Notation

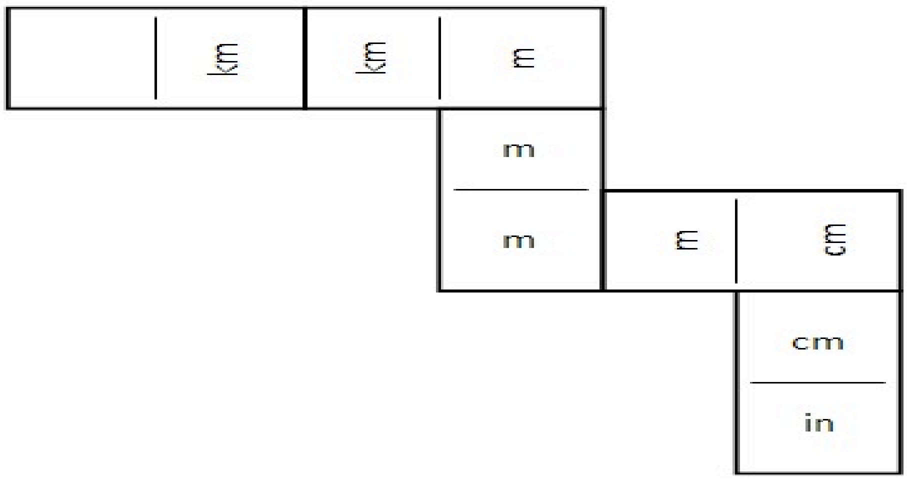
Note: The exponent is negative because the number is less than one.

Tips on Scientific Notation

- Always start counting from the decimal point
- However many spaces you moved the decimal, that's the power on 10
  - Negative Exponents
    - Small numbers
    - Count the decimal places from left to right
  - Positive Exponents
    - Larger numbers
    - Count the decimal places from right to left
    - Stop counting after the first digit in the number

APPENDIX AF: CONVERSIONOES.COM TRIAL VERSION

Conversionoes©



Conversionoes©

Conversionoes©

Which is Larger?

1 gallon of water

OR

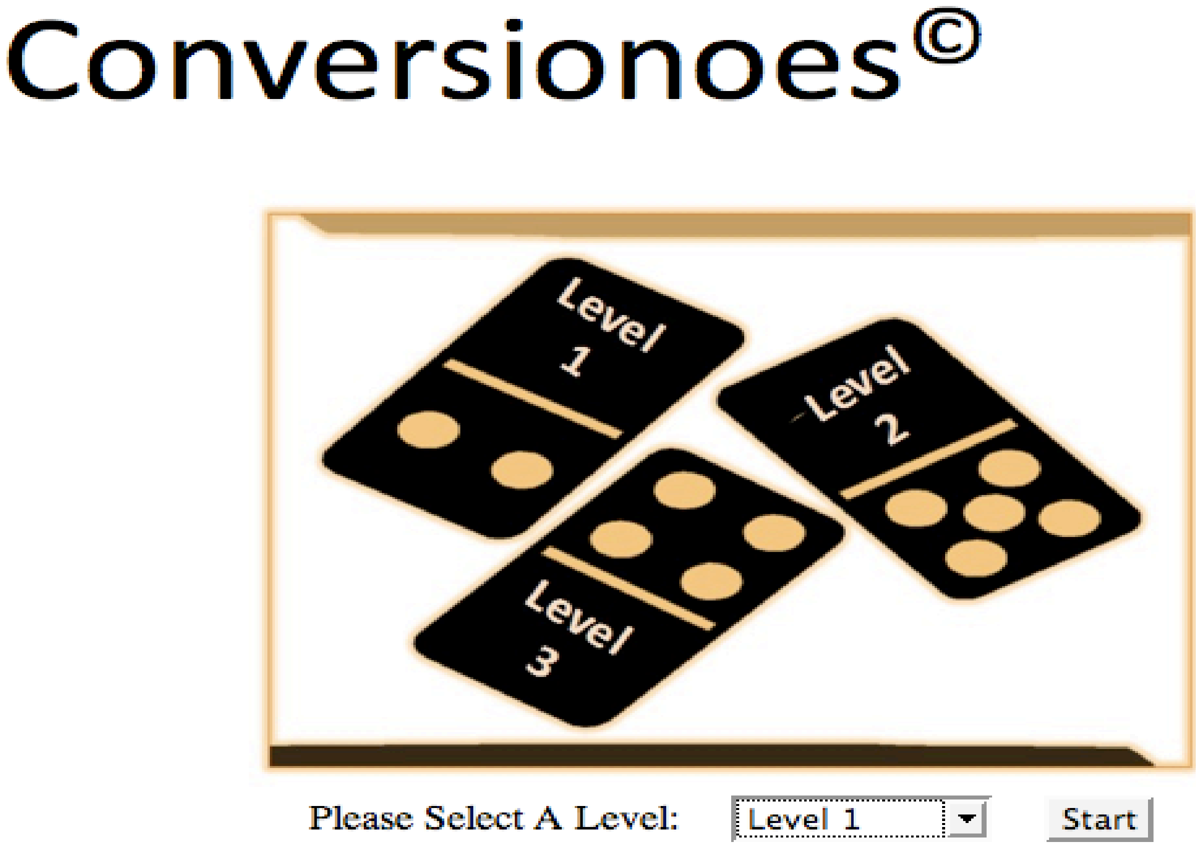
1.05 pints of water

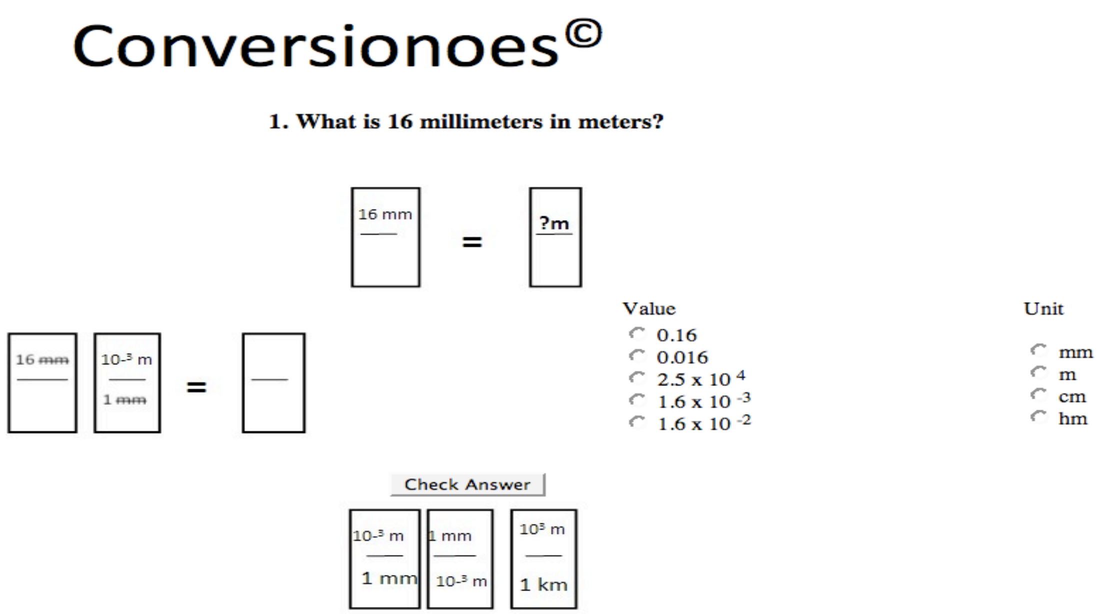
Conversionoes©

You are correct!

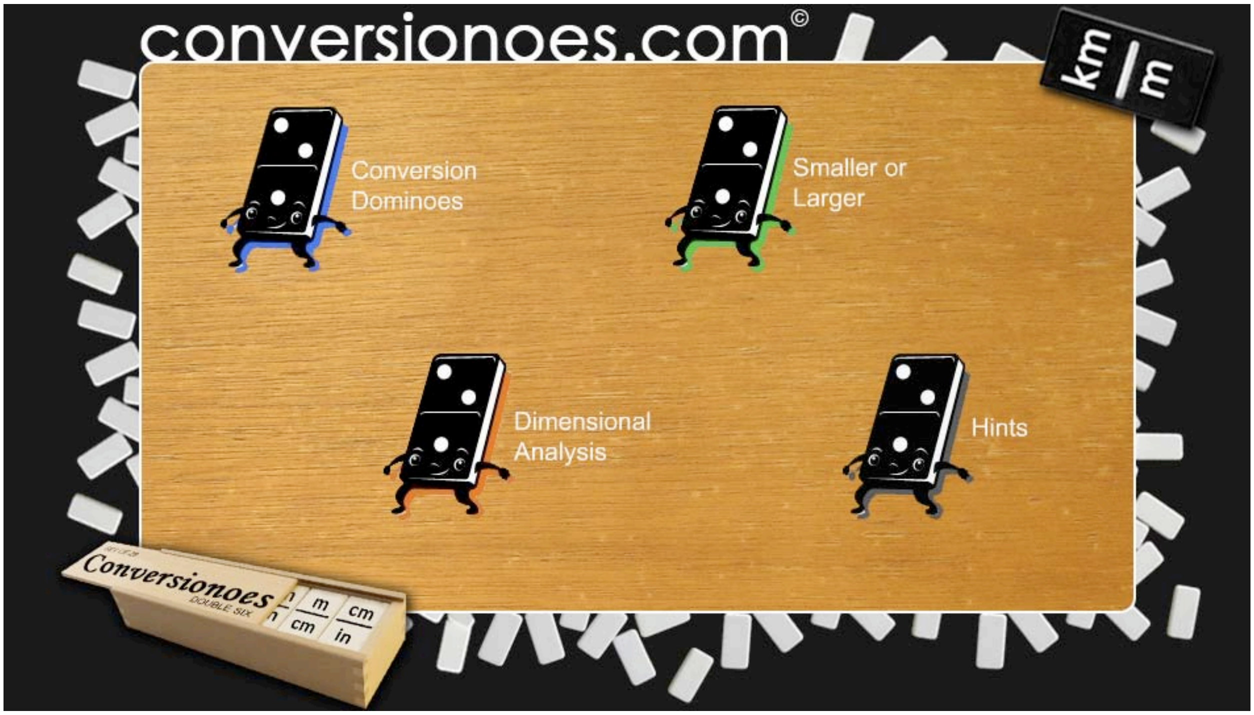
1 gallon of water

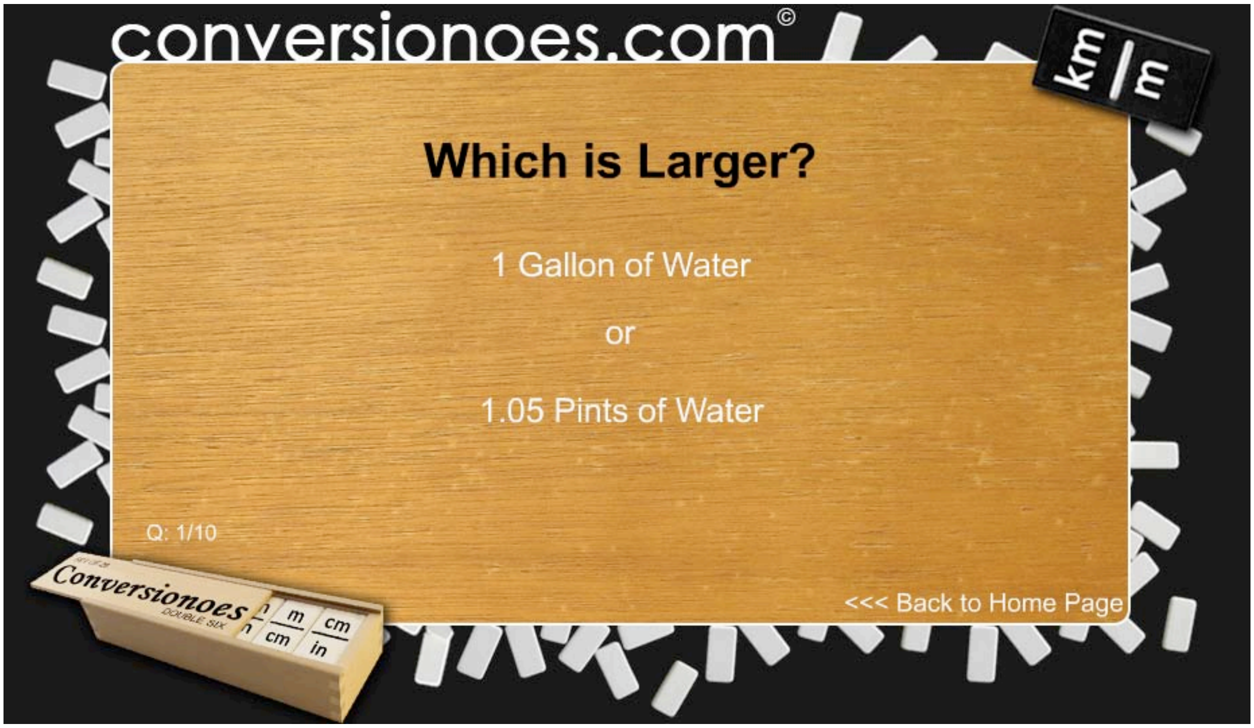
1 gal of water 1.05 pts of water


Conversionoes©
Level 1
Level 2
Level 3
Please Select A Level:
Level 1
Start


Conversionoes©
1. What is 16 millimeters in meters?
16 mm
=
?m
16 mm
10-3 m
1 mm
=
Value
0.16
0.016
2.5 x 10 4
1.6 x 10 -3
1.6 x 10 -2
Unit
mm
m
cm
hm
Check Answer
10-3 m
1 mm
1 mm
10-3 m
103 m
1 km

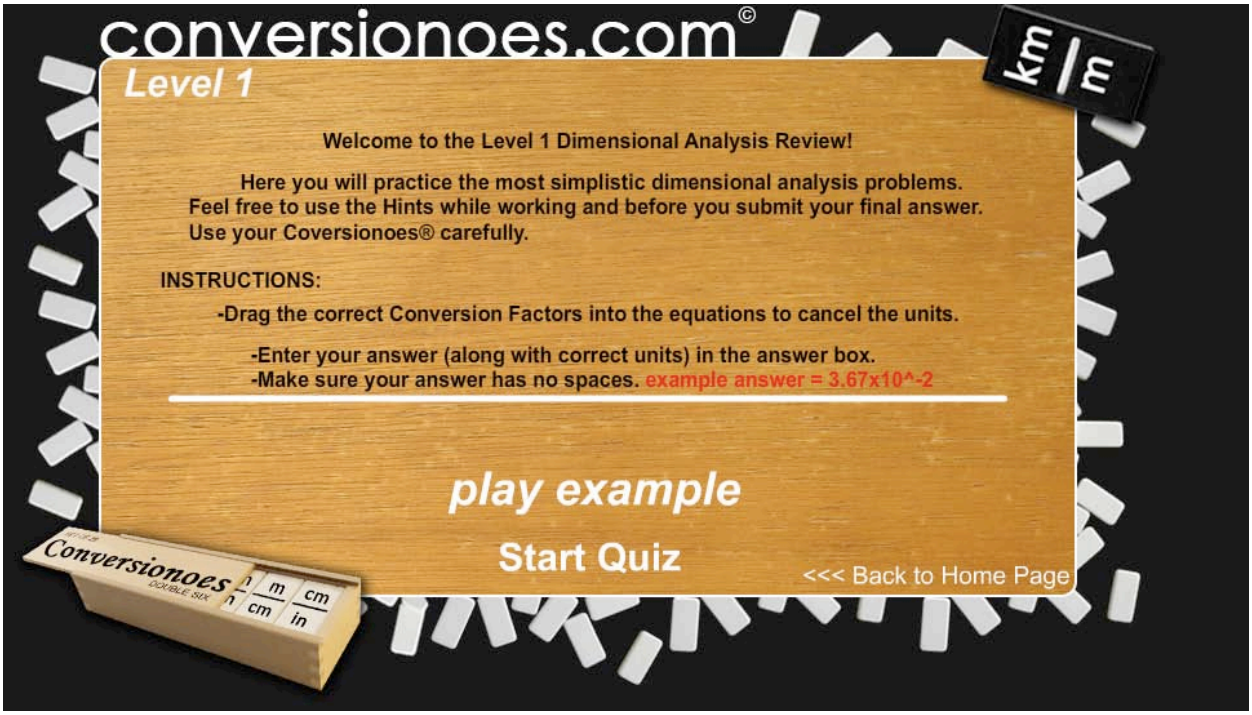
APPENDIX AG: CONVERSIONOES-FULL VERSION

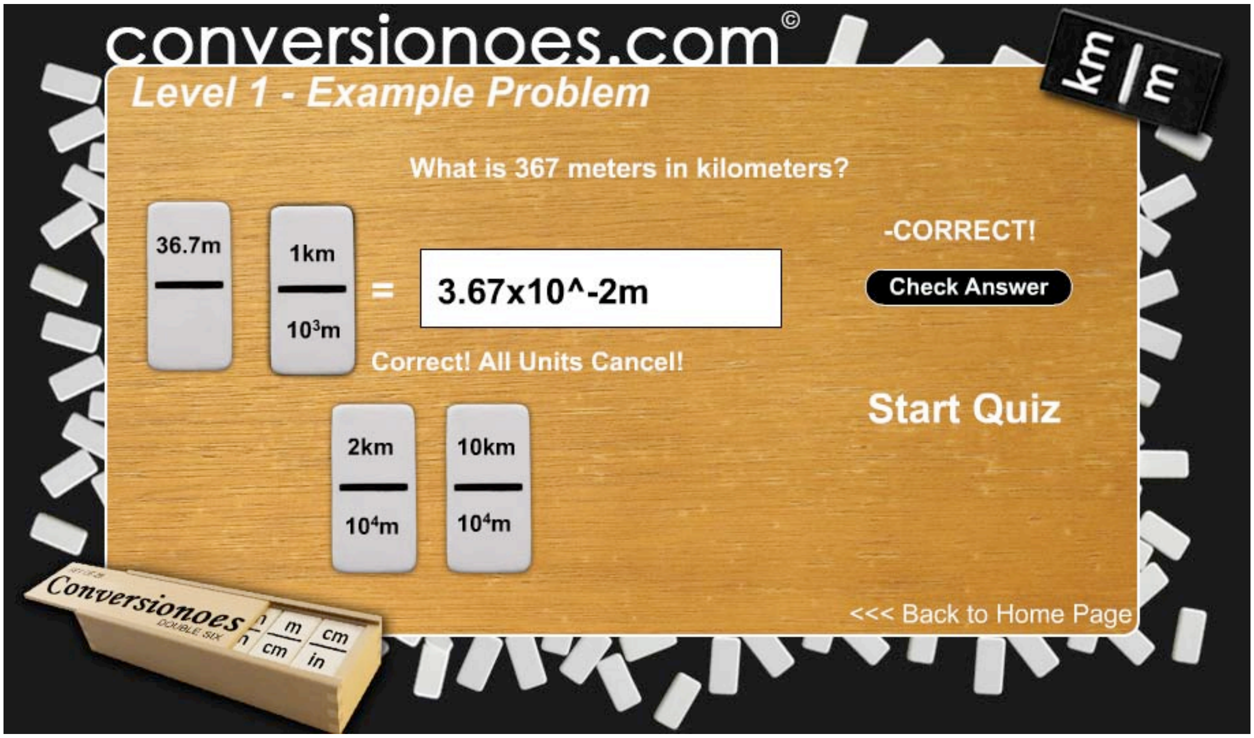



conversionoes.com©
km/m
Which is Larger?
1 Gallon of Water
or
1.05 Pints of Water
Q: 1/10
Conversionoes
<<< Back to Home Page


conversionoes.com©
km/m
CORRECT!
1 gal
of water
1.04 pts
of water
NEXT>>>
Q: 1/10
Conversionoes
<<< Back to Home Page


conversionoes.com©
km
m
level
1
level
2
level
3
Please Select A Level
<<< Back to Home Page
Conversionoes
DOUBLE SIX
m
cm
cm
in


conversionoes.com©
km
m
Level 1
Welcome to the Level 1 Dimensional Analysis Review!
Here you will practice the most simplistic dimensional analysis problems.
Feel free to use the Hints while working and before you submit your final answer.
Use your Coversionoes® carefully.
INSTRUCTIONS:
-Drag the correct Conversion Factors into the equations to cancel the units.
-Enter your answer (along with correct units) in the answer box.
-Make sure your answer has no spaces. example answer = 3.67x10^-2
play example
Start Quiz
<<< Back to Home Page
Conversionoes
DOUBLE SIX
m
cm
cm
in


conversionoes.com©
Level 1 - Example Problem
What is 367 meters in kilometers?
36.7m
1km
10³m
=
3.67x10^-2m
-CORRECT!
Check Answer
Correct! All Units Cancel!
Start Quiz
2km
10⁴m
10km
10⁴m
Conversionoes
DOUBLE SIX
m
cm
cm
in
km
m
<<< Back to Home Page


conversionoes.com©
cm
in
HINTS
Problem Solving Solutions
Using Your Calculator
Scientific Notation
Significant Figures
Conversionoes
DOUBLE SIX
m
cm
cm
in
km
m
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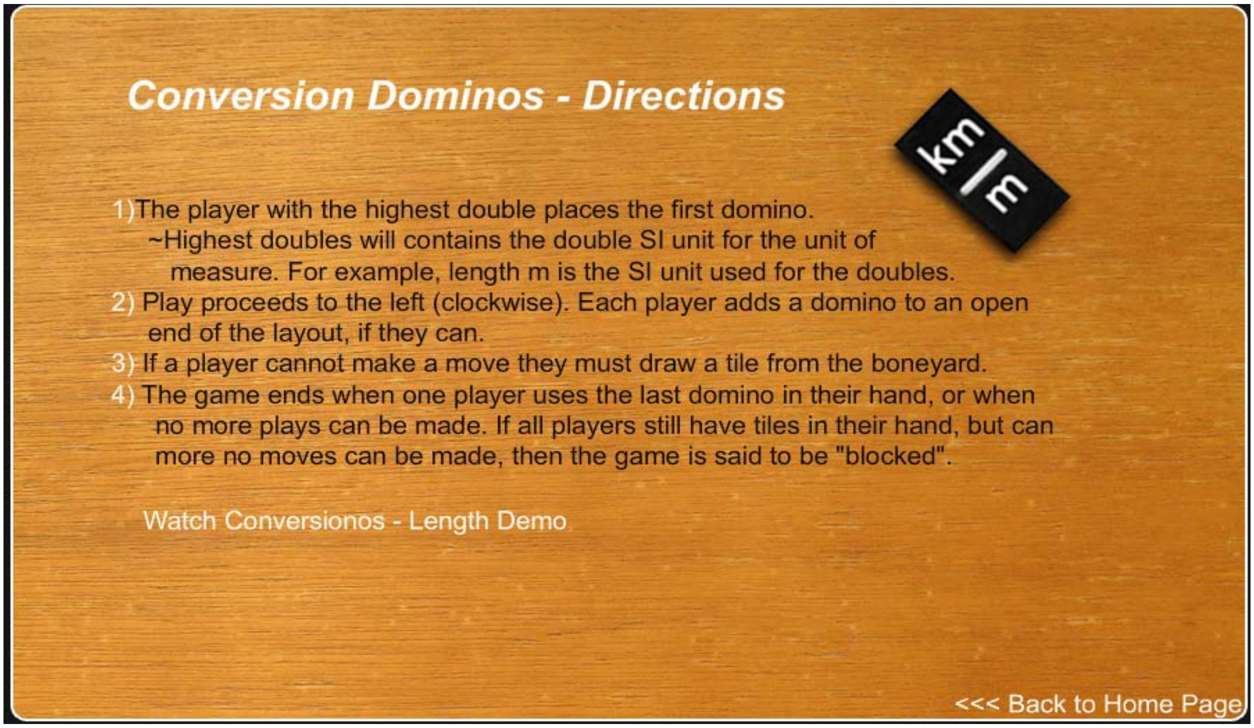
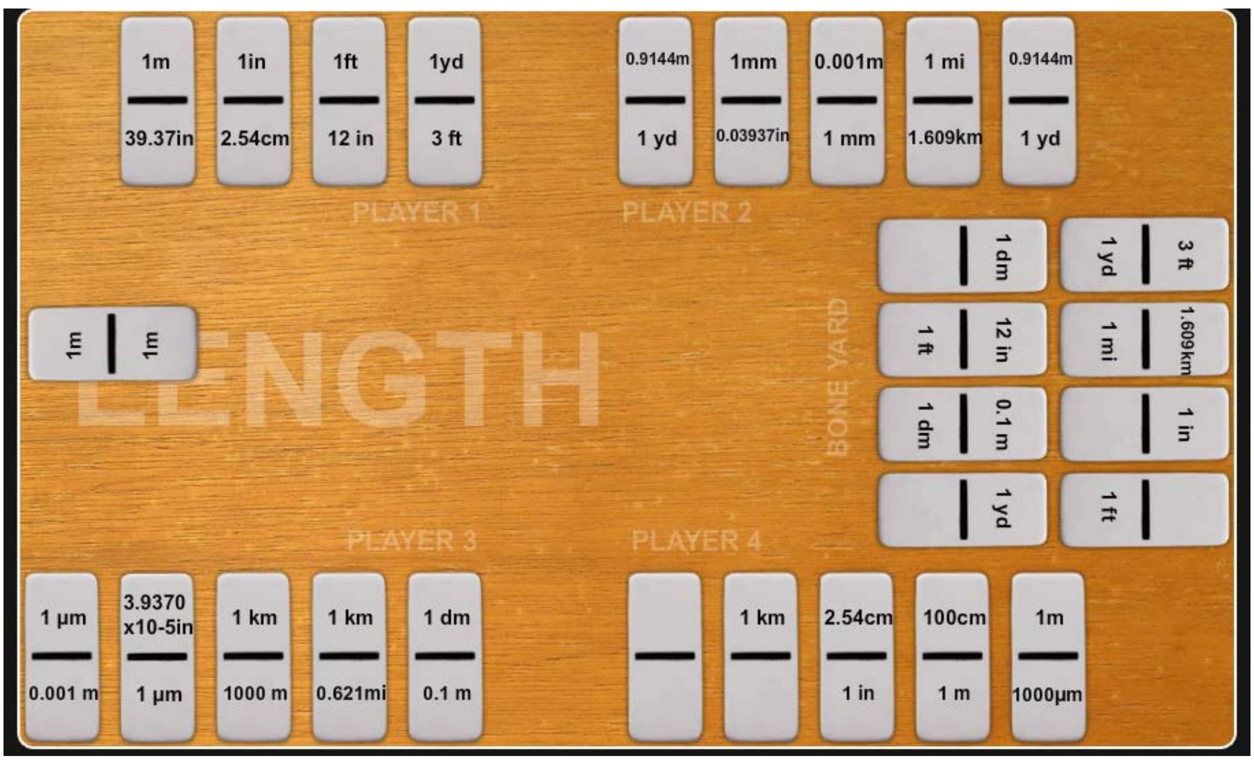

Conversion Dominos - Directions
km
m
1)The player with the highest double places the first domino.
~Highest doubles will contains the double SI unit for the unit of measure. For example, length m is the SI unit used for the doubles.
2) Play proceeds to the left (clockwise). Each player adds a domino to an open end of the layout, if they can.
3) If a player cannot make a move they must draw a tile from the boneyard.
4) The game ends when one player uses the last domino in their hand, or when no more plays can be made. If all players still have tiles in their hand, but can more no moves can be made, then the game is said to be "blocked".
Watch Conversionos - Length Demo
<<< Back to Home Page


1m
39.37in
1in
2.54cm
1ft
12 in
1yd
3 ft
0.9144m
1 yd
1mm
0.03937in
0.001m
1 mm
1 mi
1.609km
0.9144m
1 yd
PLAYER 1
PLAYER 2
1m
1m
LENGTH
BONE YARD
1 dm
1 yd
3 ft
1 ft
12 in
1 mi
1.609km
1 dm
0.1 m
1 in
1 yd
1 ft
PLAYER 3
PLAYER 4
1 µm
0.001 m
3.9370 x10-5in
1 µm
1 km
1000 m
1 km
0.621mi
1 dm
0.1 m
1 km
2.54cm
1 in
100cm
1 m
1m
1000µm

APPENDIX AH: CONVERSIONOES-DIMENSIONAL ANALYSIS LEVEL 1 DATA

ID	Quiz Start	Quiz End	Level	Right	Wrong	% Correct
School A						
17	5/15/09 7:35 AM	5/15/09 7:44 AM	1	10	0	100.00%
18	5/15/09 7:36 AM		1			
19	5/15/09 7:37 AM		1			
20	5/15/09 7:37 AM	5/15/09 7:46 AM	1	5	5	50.00%
21	5/15/09 7:37 AM	5/15/09 7:46 AM	1	10	0	100.00%
22	5/15/09 7:37 AM	5/15/09 7:47 AM	1	1	9	10.00%
23	5/15/09 7:38 AM		1			
24	5/15/09 7:39 AM	5/15/09 7:51 AM	1	6	4	60.00%
32	5/15/09 7:40 AM	5/15/09 8:01 AM	1	6	4	60.00%
33	5/15/09 7:40 AM	5/15/09 7:46 AM	1	10	0	100.00%
34	5/15/09 7:40 AM	5/15/09 7:46 AM	1	5	5	50.00%
35	5/15/09 7:40 AM	5/15/09 7:56 AM	1	9	1	90.00%
36	5/15/09 7:40 AM	5/15/09 7:46 AM	1	10	0	100.00%
37	5/15/09 7:40 AM	5/15/09 7:51 AM	1	6	4	60.00%
38	5/15/09 7:40 AM	5/15/09 7:47 AM	1	1	9	10.00%
39	5/15/09 7:40 AM	5/15/09 7:46 AM	1	5	5	50.00%
					School A's Avg	64.62%
School B						
50	5/15/09 1:05 PM	5/15/09 1:18 PM	1	3	7	30.00%
51	5/15/09 1:05 PM	5/15/09 1:18 PM	1	1	9	10.00%
52	5/15/09 1:06 PM	5/15/09 1:17 PM	1	2	8	20.00%
53	5/15/09 1:06 PM	5/15/09 1:12 PM	1	3	7	30.00%
54	5/15/09 1:06 PM	5/15/09 1:14 PM	1	3	7	30.00%
55	5/15/09 1:06 PM	5/15/09 1:12 PM	1	1	9	10.00%
56	5/15/09 1:07 PM	5/15/09 1:13 PM	1	2	8	20.00%
57	5/15/09 1:08 PM	5/15/09 1:20 PM	1	4	6	40.00%
58	5/15/09 1:08 PM	5/15/09 1:20 PM	1	4	6	40.00%
					School B's Avg	25.56%

APPENDIX AI: DIMENSIONAL ANALYSIS DATA-LEVEL 2

ID	Quiz Start	Quiz End	Level	Right	Wrong	% Correct
School A						
25	5/15/09 7:39 AM	5/15/09 8:01 AM	2	6	4	60.00%
26	5/15/09 7:40 AM	5/15/09 7:56 AM	2	9	1	90.00%
27	5/15/09 7:40 AM	5/15/09 7:46 AM	2	5	5	50.00%
28	5/15/09 7:40 AM	5/15/09 7:46 AM	2	10	0	100.00%
29	5/15/09 7:40 AM	5/15/09 7:47 AM	2	1	9	10.00%
30	5/15/09 7:40 AM	5/15/09 7:51 AM	2	6	4	60.00%
31	5/15/09 7:40 AM		2			
40	5/15/09 7:43 AM		2			
41	5/15/09 7:45 AM	5/15/09 7:56 AM	2	10	0	100.00%
42	5/15/09 7:45 AM	5/15/09 7:55 AM	2	4	6	40.00%
43	5/15/09 7:46 AM	5/15/09 7:56 AM	2	10	0	100.00%
44	5/15/09 7:46 AM	5/15/09 7:50 AM	2	10	0	100.00%
45	5/15/09 7:46 AM	5/15/09 7:55 AM	2	9	1	90.00%
46	5/15/09 7:47 AM	5/15/09 7:54 AM	2	1	9	10.00%
47	5/15/09 7:52 AM		2			
48	5/15/09 7:57 AM	5/15/09 8:01 AM	2	10	0	100.00%
49	5/15/09 8:43 AM		2			
					School A's Avg	70.00%
School B						
59	5/15/09 1:12 PM	5/15/09 1:20 PM	2	2	8	20.00%
60	5/15/09 1:12 PM	5/15/09 1:19 PM	2	3	7	30.00%
61	5/15/09 1:12 PM	5/15/09 1:19 PM	2	3	7	30.00%
62	5/15/09 1:13 PM	5/15/09 1:18 PM	2	3	7	30.00%
63	5/15/09 1:14 PM	5/15/09 1:19 PM	2	2	8	20.00%
64	5/15/09 1:17 PM	5/15/09 1:23 PM	2	3	7	30.00%
65	5/15/09 1:18 PM	5/15/09 1:25 PM	2	3	7	30.00%
66	5/15/09 1:19 PM	5/15/09 1:31 PM	2	1	9	10.00%
					School B's Avg	25.00%

APPENDIX AJ: LARGER OR SMALLER DATA

ID	Quiz Start	Quiz End	Answer 1	Answer 2	Answer 3	Answer 4	Answer 5	Answer 6	Answer 7	Answer 8	Answer 9	Answer 10	WR	RT	% Correct
School A															
36	5/15/09 7:33 AM	5/15/09 7:36 AM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 15.2 cm index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 cup of brown rice	200 mL of milk	4	6	60.00%
38	5/15/09 7:33 AM	5/15/09 7:36 AM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	452 g of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	3	7	70.00%
39	5/15/09 7:33 AM	5/15/09 7:36 AM	1.05 pints of water	237 mL of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 15.2 cm index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	1	9	90.00%
42	5/15/09 7:33 AM	5/15/09 7:36 AM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	2	8	80.00%
43	5/15/09 7:33 AM	5/15/09 7:36 AM	1 gal. of water	237 mL of soda	453 g of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	3	7	70.00%
44	5/15/09 7:33 AM	5/15/09 7:36 AM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	5 lb bag of flour	1/4 cup of red crushed pepper	1 cup of brown rice	2 cups of milk	4	6	60.00%
45	5/15/09 7:33 AM	5/15/09 7:35 AM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	2	8	80.00%
48	5/15/09 7:35 AM	5/15/09 7:36 AM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 15.2 cm index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	0	10	100.00%
School A's Avg															76.25%

School B															
52	5/15/09 1:03 PM	5/15/09 1:06 PM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	452 g of baby powder	5 lb bag of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	200 mL of milk	6	4	40.00%
53	5/15/09 1:03 PM	5/15/09 1:05 PM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 15.2 cm index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	0	10	100.00 %
54	5/15/09 1:03 PM	5/15/09 1:06 PM	1 gal. of water	237 mL of soda	453 g of dark brown sugar	1.47 liters of laundry detergent	Length of a 5 in index card	452 g of baby powder	5 lb bag of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	4	6	60.00%
56	5/15/09 1:03 PM	5/15/09 1:05 PM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	452 g of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	3	7	70.00%
58	5/15/09 1:03 PM	5/15/09 1:08 PM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	2	8	80.00%
60	5/15/09 1:03 PM	5/15/09 1:06 PM	1 gal. of water	12 fl. oz. of soda	453 g of dark brown sugar	1.47 liters of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	200 mL of milk	4	6	60.00%
61	5/15/09 1:03 PM	5/15/09 1:08 PM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	1.47 liters of laundry detergent	Length of a 15.2 cm index card	1.5 oz of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	200 mL of milk	2	8	80.00%
62	5/15/09 1:03 PM	5/15/09 1:07 PM	1 gal. of water	237 mL of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	1.5 oz of baby powder	32 oz of flour	1/4 teaspoon of red crushed pepper	1 tbsp of brown rice	2 cups of milk	3	7	70.00%
63	5/15/09 1:04 PM	5/15/09 1:06 PM	1 gal. of water	12 fl. oz. of soda	2 lbs of dark brown sugar	3.12 qt of laundry detergent	Length of a 5 in index card	452 g of baby powder	32 oz of flour	1/4 cup of red crushed pepper	1 tbsp of brown rice	2 cups of milk	4	6	60.00%
School B's Avg															68.89%

APPENDIX AK: PRE SURVEY DATA-CONTROL GROUP-SCHOOL A

Student	General Chemistry is one of my favorite classes I am taking this semester.	I am doing well in my General Chemistry class.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook or any handout/worksheet.	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.
Student 1	3	3	1	1	1
Student 2	4	5	5	4	4
Student 3	2	3	2	2	1
Student 4	2	3	1	3	2
Student 5	3	4	3	4	3
Student 6	5	5	4	5	5
Student 7	1	3	2	3	1
Student 8	3	4	4	5	4
Student 9	2	4	2	3	3
Student 10	5	5	3	4	3
Student 11	2	4	3	2	4
Average	**2.91**	**3.91**	**2.73**	**3.27**	**2.82**
STD DEV	**1.300**	**0.831**	**1.272**	**1.272**	**1.401**

Student	I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.	Presently I understand the relationship between conversion factors and how to use them to solve various problems.	Before I select my final answer of a dimensional analysis (unit conversions) problem, I double check my answer to see if it makes sense.	My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures.	While working on my homework if I do not understand a concept I'll search the Internet for tutorials or some form of help.
Student 1	5	3	2	3	2
Student 2	5	5	5	4	4
Student 3	4	3	2	3	1
Student 4	5	1	3	2	2
Student 5	3	3	4	3	2
Student 6	5	4	3	3	3
Student 7	3	3	4	4	2
Student 8	3	4	4	2	2
Student 9	1	2	3	3	5
Student 10	5	5	5	4	4
Student 11	5	4	1	5	1
Average	**4.00**	**3.36**	**3.27**	**3.27**	**2.55**
STD DEV	**1.342**	**1.206**	**1.272**	**0.905**	**1.293**

Student	What is your gender?		
Student 1	Female		
Student 2	Male	Student 6	Male
Student 3	Male	Student 7	Female
Student 4	Male	Student 8	Female
Student 5	Female	Student 9	Female
		Student 10	Female
		Student 11	Male

APPENDIX AL: PRE SURVEY DATA-TREATMENT GROUP-SCHOOL A

Student	General Chemistry is one of my favorite classes I am taking this semester.	I am doing well in my General Chemistry class.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook or any handout/worksheet.	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.
Student 1	1	3	3	3	3
Student 2	4	5	3	3	3
Student 3	2	3	3	3	3
Student 4	1	2	2	3	3
Student 5	1	3	3	3	1
Student 6	1	1	3	3	2
Student 7	5	4	3	4	3
Student 8	1	3	1	1	1
Student 9	1	2	2	1	1
Student 10	3	3	3	4	4
Student 11	1	3	3	2	1
Average	**1.91**	**2.91**	**2.64**	**2.73**	**2.27**
STD DEV	**1.446**	**1.044**	**0.674**	**1.009**	**1.104**

Student	I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.	Presently I understand the relationship between conversion factors and how to use them to solve various problems.	Before I select my final answer of a dimensional analysis (unit conversions) problem, I double check my answer to see if it makes sense.	My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures.	While working on my homework if I do not understand a concept I'll search the Internet for tutorials or some form of help.
Student 1	4	4	3	3	2
Student 2	3	3	2	3	1
Student 3	3	3	4	3	3
Student 4	3	3	3	3	3
Student 5	3	3	3	4	4
Student 6	2	1	3	4	1
Student 7	4	5	4	4	2
Student	4	2	3	1	1

8					
Student 9	4	1	2	2	2
Student 10	4	4	4	4	3
Student 11	3	3	2	2	2
Average	**3.36**	**2.91**	**3.00**	**3.00**	**2.18**
STD DEV	**0.674**	**1.221**	**0.775**	**1.000**	**0.982**

Student	What is your gender?
Student 1	Female
Student 2	Female
Student 3	Female
Student 4	Male
Student 5	Male
Student 6	Male
Student 7	Male
Student 8	Male
Student 9	Female
Student 10	Male
Student 11	Male

APPENDIX AM: PRE SURVEY DATA-CONTROL GROUP-SCHOOL B

Student	General Chemistry is one of my favorite classes I am taking this semester.	I am doing well in my General Chemistry class.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook or any handout/worksheet.	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.
Student 1	3	3	3	4	4
Student 2	3	4	3	4	3
Student 3	2	4	3	3	3
Student 4	2	4	1	2	3
Student 5	3	4	4	3	3
Student 6	2	3	4	2	2
Average	2.50	3.67	3.00	3.00	3.00
STD DEV	0.548	0.516	1.095	0.894	0.632

Student	I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.	Presently I understand the relationship between conversion factors and how to use them to solve various problems.	Before I select my final answer of a dimensional analysis (unit conversions) problem, I double check my answer to see if it makes sense.	My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures.	While working on my homework if I do not understand a concept I'll search the Internet for tutorials or some form of help.
Student 1	4	4	2	4	3
Student 2	4	3	4	4	2
Student 3	3	3	3	2	1
Student 4	4	4	4	3	3
Student 5	4	4	4	3	2
Student 6	3	3	3	3	3
Average	3.67	3.50	3.33	3.17	2.33
STD DEV	0.516	0.548	0.816	0.753	0.816

Student	What is your gender?
Student 1	Female
Student 2	Male
Student 3	Female
Student 4	Female
Student 5	Male
Student 6	Male

APPENDIX AN: PRE SURVEY DATA-TREATMENT GROUP-SCHOOL B

Student	General Chemistry is one of my favorite classes I am taking this semester.	I am doing well in my General Chemistry class.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that from my teacher's lecture(s) on dimensional analysis (unit conversions) that I can answer the problems in my textbook or any handout/worksheet.	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.
Student 1	1	3	4	4	3
Student 2	1	2	3	4	4
Student 3	5	3	3	4	3
Student 4	3	4	4	4	4
Student 5	1	4	4	3	3
Student 6	2	3	3	3	3
Student 7	3	3	3	3	3
Student 8	3	3	3	4	4
Average	2.38	3.13	3.38	3.63	3.38
STD DEV	1.408	0.641	0.518	0.518	0.518

Student	I have a good perception of size when introduced to a new unit of measure. For example, I know which is smaller if I had to determine between a centimeter and a yard.	Presently I understand the relationship between conversion factors and how to use them to solve various problems.	Before I select my final answer of a dimensional analysis (unit conversions) problem, I double check my answer to see if it makes sense.	My current textbook provides enough information for me to answer any questions I may have after my teacher's lectures.	While working on my homework if I do not understand a concept I'll search the Internet for tutorials or some form of help.
Student 1	5	3	1	3	5
Student 2	-	4	5	4	2
Student 3	3	3	4	2	4
Student 4	2	4	3	3	2
Student 5	4	4	4	3	5
Student 6	5	3	4	5	3
Student 7	4	4	4	4	2
Student 8	4	4	2	4	3
Average	3.86	3.63	3.38	3.50	3.25
STD DEV	1.069	0.518	1.302	0.926	1.282

Student	What is your gender?
Student 1	Female
Student 2	Female
Student 3	Female
Student 4	Male
Student 5	Female
Student 6	Female
Student 7	Male
Student 8	Female

APPENDIX AO: POST SURVEY DATA-CONTROL GROUP- SCHOOL A

Student	I plan to pursue a career in science, technology or engineering when I graduate high school.	I have used computer software and/or chemistry related websites in chemistry class this semester.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.	I found the Conversionoes (dimensional analysis) software helped enhance my understanding of dimensional analysis (unit conversions).	What did you find helpful about the software?
Student 1	3	2	4	4	3	-
Student 2	2	2	2	2	2	-
Student 3	3	1	1	1	1	-
Student 4	1	3	3	2	3	-
Student 5	3	3	3	3	3	-
Student 6	1	1	-	-	-	-
Student 7	1	1	2	1	3	-
Student 8	1	2	4	3	3	-
Student 9	4	3	3	3	N/A	-
Average	2.11	2.00	2.75	2.38	2.57	
STD DEV	1.167	0.866	1.035	1.061	0.787	

Student	Which section(s) of the software did you use?	The larger or smaller portion of the Conversionoes software helped me visualize and understand units.	Before I submitted my final answer when solving dimensional analysis (unit conversions) problems (either using the software or the worksheet activity), I double checked my answers to see if they made sense.	I used the hints section of the software or asked a group member when I needed help with a problem.	I found the hints section helpful.	Which hints did you use?
Student 1	None	N/A	3	2	N/A	None
Student 2	None	2	3	1	1	None
Student 3	None	N/A	1	1	N/A	None
Student 4	-	-	-	-	-	None
Student 5	-	3	3	4	5	None
Student 6	-	-	5	5	5	None
Student 7	-	-	-	-	-	None
Student 8	-	3	4	2	3	None
Student 9	-	4	3	3	N/A	None
Average		3.00	3.14	2.57		
STD DEV		0.816	1.215	1.512		

Student	To improve the Conversionoes software I would change the following:	What is your gender?
Student 1	-	Female
Student 2	-	Male
Student 3	-	Male
Student 4	-	-
Student 5	-	Male
Student 6	-	Male
Student 7	-	-
Student 8	-	Female
Student 9	-	Female

APPENDIX AP: POST SURVEY DATA-TREATMENT GROUP-CONTROL A

Student	I plan to pursue a career in science, technology or engineering when I graduate high school.	I have used computer software and/or chemistry related websites in chemistry class this semester.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.	I found the Conversionoes (dimensional analysis) software helped enhance my understanding of dimensional analysis (unit conversions).	What did you find helpful about the software?
Student 1	5	1	3	3	4	the software was neat so it kept me interested the whole time.
Student 2	5	4	5	5	5	It helped to remind me the steps to follow when going through the problem.
Student 3	2	4	2	2	4	The hints helped me use my calculator.
Student 4	3	4	4	3	3	That it already gives the conversions so that it is easier to solve the problem.
Student 5	3	2	4	3	3	It helped me understand the problems better.
Student 6	2	3	2	1	4	That it gave you hints when and if you needed it and it just shows the format for you to help you understand it better.
Student 7	1	1	3	3	3	Explained everything out very well.
Student 8	3	3	3	3	4	That it helped me to find how to use my calculator
Student 9	1	1	4	3	3	idk
Average	2.78	2.56	3.33	2.89	3.67	
STD DEV	1.481	1.333	1.000	1.054	0.707	

Student	Which section(s) of the software did you use?	The larger or smaller portion of the Conversionoes software helped me visualize and understand units.	Before I submitted my final answer when solving dimensional analysis (unit conversions) problems (either using the software or the worksheet activity), I double checked my answers to see if they made sense.	I used the hints section of the software or asked a group member when I needed help with a problem.	I found the hints section helpful.	Which hints did you use?
Student 1	Larger or Smaller, Dimensional Analysis	5	5	1	N/A	None
Student 2	Larger or Smaller, Dimensional Analysis	5	5	2	N/A	None
Student 3	Larger or Smaller, Dimensional Analysis, Hints	4	3	4	5	Putting the final answer in significant figures, Putting the final answer in

						scientific notation, Using your calculator solve dimensional analysis problems, Dimensional analysis problem solving strategies
Student 4	Larger or Smaller, Dimensional Analysis	5	4	3	N/A	None
Student 5	Larger or Smaller, Dimensional Analysis	4	2	2	N/A	None
Student 6	Larger or Smaller, Dimensional Analysis, Hints	3	4	3	3	Dimensional analysis problem solving strategies
Student 7	Larger or Smaller, Dimensional Analysis, Hints	4	3	3	5	Putting the final answer in significant figures
Student 8	Larger or Smaller, Dimensional Analysis, Hints	4	4	5	5	Putting the final answer in significant figures, Putting the final answer in scientific notation, Using your calculator to help solve dimensional analysis problems, Dimensional analysis problem solving strategies
Student 9	Larger or Smaller, Dimensional Analysis, Hints	3	3	1	2	None
Average		4.11	3.67	2.67	4.00	
STD DEV		0.782	1.000	1.323	1.414	

Student	To improve the Conversionoes software I would change the following:	What is your gender?
Student 1	-	Female
Student 2	None of it	Male
Student 3	-	Male
Student 4	-	Female
Student 5	-	Male
Student 6	Wouldn"t change anything	Female
Student 7	-	Male
Student 8	The way I did my problems.	Male
Student 9	-	Male

APPENDIX AQ: POST SURVEY DATA-CONTROL GROUP-SCHOOL B

Student	I plan to pursue a career in science, technology or engineering when I graduate high school.	I have used computer software and/or chemistry related websites in chemistry class this semester.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.	I found the Conversionoes (dimensional analysis) software helped enhance my understanding of dimensional analysis (unit conversions).	What did you find helpful about the software?
Student 1	1	3	3	3	N/A	-
Student 2	3	4	4	4	N/A	-
Student 3	5	3	4	4	N/A	-
Student 4	1	3	3	2	N/A	-
Student 5	5	5	3	3	N/A	-
Average	3.00	3.60	3.40	3.20		
STD DEV	2.000	0.894	0.548	0.837		

Student	Which section(s) of the software did you use?	The larger or smaller portion of the Conversionoes software helped me visualize and understand units.	Before I submitted my final answer when solving dimensional analysis (unit conversions) problems (either using the software or the worksheet activity), I double checked my answers to see if they made sense.	I used the hints section of the software or asked a group member when I needed help with a problem.	I found the hints section helpful.	Which hints did you use?
Student 1	None	N/A	-	-	N/A	None
Student 2	None	N/A	4	3	N/A	None
Student 3	None	N/A	3	2	N/A	None
Student 4	None	N/A	3	3	N/A	None
Student 5	None	N/A	1	1	N/A	None
Average			2.75	2.25		
STD DEV			1.258	0.957		

Student	To improve the Conversionoes software I would change the following:	What is your gender?
Student 1	-	Male
Student 2	-	Female
Student 3	-	Male
Student 4	-	Male
Student 5	-	Female

APPENDIX AR: POST SURVEY DATA-TREATMENT GROUP-SCHOOL B

Student	I plan to pursue a career in science, technology or engineering when I graduate high school.	I have used computer software and/or chemistry related websites in chemistry class this semester.	Presently I understand the scientific concept of dimensional analysis (unit conversions).	Presently I feel that I can explain to a fellow classmate how to solve a dimensional analysis (unit conversions) problem.	I found the Conversionoes (dimensional analysis) software helped enhance my understanding of dimensional analysis (unit conversions).	What did you find helpful about the software?
Student 1	2	4	2	2	2	-
Student 2	3	4	3	4	4	-
Student 3	2	3	3	3	4	-
Student 4	4	3	4	4	3	-
Student 5	3	5	3	1	3	The information on scientific notation was very helpful.
Student 6	3	4	4	4	3	I liked how the software gave you examples of your problems and that it gave you word problems.
Student 7	3	1	4	3	4	Set up conversions where they were less confusing to understand and also the videos helped me.
Student 8	2	2	3	2	5	I didn't understand it very well but I do now after watching the video
Student 9	3	5	4	4	5	It showed me how to work the problem out 3.
Average	2.78	3.44	3.33	3.00	3.67	
STD DEV	0.667	1.333	0.707	1.118	1.000	

Student	Which section(s) of the software did you use?	The larger or smaller portion of the Conversionoes software helped me visualize and understand units.	Before I submitted my final answer when solving dimensional analysis (unit conversions) problems (either using the software or the worksheet activity), I double checked my answers to see if they made sense.	I used the hints section of the software or asked a group member when I needed help with a problem.	I found the hints section helpful.	Which hints did you use?
Student 1	Larger or Smaller, Dimensional Analysis	4	2	2	N/A	None
Student 2	Larger or Smaller, Dimensional Analysis	4	4	2	N/A	None

Student 3	Dimensional Analysis	3	2	1	N/A	None
Student 4	Larger or Smaller, Dimensional Analysis	3	3	2	N/A	None
Student 5	Larger or Smaller, Dimensional Analysis	4	4	4	5	Dimensional analysis problem solving strategies
Student 6	Larger or Smaller, Dimensional Analysis	4	3	2	3	None
Student 7	Larger or Smaller, Dimensional Analysis, Hints	4	3	2	4	Putting the final answer in significant figures, Putting the final answer in scientific notation
Student 8	Larger or Smaller, Dimensional Analysis, Hints	4	4	4	5	Putting the final answer in significant figures, Putting the final answer in scientific notation
Student 9	Larger or Smaller, Dimensional Analysis	5	5	2	N/A	None
Average		3.89	3.33	2.33	4.25	
STD DEV		0.601	1.000	1.000	0.957	

Student	To improve the Conversionoes software I would change the following:	What is your gender?
Student 1	-	Male
Student 2	-	Male
Student 3	make the numbers bigger. maybe have speaking on the questions.	Male
Student 4	-	Male
Student 5	-	Female
Student 6	Give you a scratch pad to allow you to do work.	Female
Student 7	maybe make it look more fun.	Female
Student 8	-	Female
Student 9	-	Female

APPENDIX AS: PRE TEST SAMPLE

Please Show Your Work!!

Pre-Test

1. Convert 16 millimeters to it equivalent in meters.

16mm | 1 m / 1000 mm = .016m

2. Your friend invites you to a Lord of the Rings movie marathon which should last approximately 13 hours. How long will you spend watching these movies in minutes?

13 hours | 60 min / 1 hour = 780 min

3. How many liters are 630 gallons of juice?

630g | 1 liter / 3.7854 g = 166.429 L

4. You downloaded a recipe from the Internet for sugar cookies and noticed that all measurements are done in the metric system. How many cups of flour will you need to meet the equivalent of 908 grams

908g | 16 ounces / 453.54 g | 1 cup / 8 ounces = 4.004 cups

5. The recommended adult dosage of an over-the-counter pain reliever is 5 mg/kg of body mass. Calculate the dosage in milligram for a 175 pound person.

175 lbs | 1 Kilogram / 2.2046 lbs = 79.379 mg

6. A football field is exactly 100 yards long, what is its length in inches?

100yds | 3 ft / 1 yd | 12 in / 1 ft = 3600 in

APPENDIX AT: POST TEST SAMPLE

Please Show Your Work!!

Post-Test

1. Express 5 megagrams to its equivalent in grams.

2. The distance walking around the average high school three times is 0.75 miles. Convert that distance into feet?

$$\frac{0.75\text{mi} \mid 5280\text{ft}}{\mid 1\text{mi}} = 3960\text{ft}$$

3. Shaquille O'Neal's basketball sneaker is 37 inches long. How long is his sneaker in millimeters?

$$\frac{37\text{in} \mid 2.54\text{cm} \mid 10^{-2}\text{m}}{\mid 1\text{in} \mid 1\text{cm}} = .9398\text{millimeters}$$

4. The mass of a gemstone is measured in carats where 1 carat equals 0.215 grams. If the annual worldwide production of aquamarine is 6.5 million carats, how many kilograms does this represent?

$$\frac{6.5\text{ carats} \mid 0.215\text{g} \mid 10^{3}\text{kg}}{\mid 1\text{carat} \mid 1\text{g}} = 1397.5\text{ Kg}$$

5. How many miles could you drive for $20 if the gas mileage of your car is 18 km/liter of gas and the price is $2.97/gallon?

6. Dry sand has a density of 1.5 g/cm^3. A child's sandbox measuring 6.0 ft by 5.0 ft is filled with sand to a depth of 8.0 inches. What is the mass of sand in kilograms?

$$\frac{1.5\text{g/cm}^3 \mid 10^{3}\text{kg}}{\mid 1\text{g}} = 1500\text{ Kg}$$

Conversion chart on back

APPENDIX AU: SUPPLEMENTAL PRACTICE PROBLEMS

Practice Problems on Unit Conversion
Using Dimensional Analysis (Factor Label Method)

These are practice problems. It is assumed that you have already been introduced to the method of "dimensional analysis." Answers are provided at the end of this document. You should look at the question, work it out *on paper* (not in your head), before checking the answers at the end. The purpose of these problems is not merely to get the right answer, but to practice writing out the dimensional analysis setup. We will be using this method all semester and I will be asking for your setups, so don't just work out an answer on your calculator without writing out a setup.

In these practice problems, I am going to ask you to stick to ONLY the following conversions between the English and metric system (these are the only conversions that I will give you on exams). In some cases you can look up conversions elsewhere, but I would rather you didn't. I want you to learn how to make conversions that take more than one single step.

1 inch = 2.54 cm exactly	**1 lb = 454 g**	**1 qt = 0.946 L**	
1 mi = 5280 ft		**1 qt = 2 pt**	**4qt = 1 gal**

You should also remember that 1 cc = 1 cm^3 = 1 mL exactly. (This is a conversion you need to know.)

For all problems, please ***show your dimensional analysis setup and give your answer to the correct significant figures.*** Remember you can use any of the conversions shown above.

1. Convert 3598 grams into pounds.
2. Convert 231 grams into ounces.
3. A beaker contains 578 mL of water. What is the volume in quarts?
4. How many ng are there in $5.27\text{x}10^{-13}$ kg?
5. What is 7.86 x 10^{-2} kL in dL?
6. What is 0.0032 gallons in cL?
7. A box measures 3.12 ft in length, 0.0455 yd in width and 7.87 inches in height. What is its volume in cubic centimeters?
8. A block occupies 0.2587 ft^3. What is its volume in mm^3?
9. If you are going 55 mph, what is your speed in nm per second?
10. If the density of an object is 2.87 x 10^{-4} lbs/cubic inch, what is its density in g/mL?

Answers are on the next page.

Answers:

1. $x \text{ lb} = 3598 \text{ g} \left(\frac{1 \text{ lb}}{454 \text{ g}}\right) = 7.93 \text{ lb}$

2. $x \text{ oz} = 231 \text{ g} \left(\frac{1 \text{ lb}}{454 \text{ g}}\right)\left(\frac{16 \text{ oz}}{1 \text{ lb}}\right) = 8.14 \text{ g}$

3. $x \text{ qt} = 578 \text{ mL} \left(\frac{1 \text{ L}}{10^3 \text{ mL}}\right)\left(\frac{1 \text{ qt}}{0.946 \text{ L}}\right) = 0.611 \text{ qt}$

4. $x \text{ ng} = 5.27\text{x}10^{-13} \text{ kg} \left(\frac{10^{12} \text{ ng}}{1 \text{ kg}}\right) = 0.527 \text{ ng}$

5. $x \text{ dL} = 7.86\text{x}10^{-2} \text{ kL} \left(\frac{10^4 \text{ dL}}{1 \text{ kL}}\right) = 786 \text{ dL}$

6. $x \text{ cL} = 0.0032 \text{ gal} \left(\frac{4 \text{ qt}}{1 \text{ gal}}\right)\left(\frac{0.946 \text{ L}}{1 \text{ qt}}\right)\left(\frac{10^2 \text{ cL}}{1 \text{ L}}\right) = 1.2 \text{ cL}$

7. You should the volume of a box is calculated thus; V = L x W x H.
   First you have to convert all the dimensions to the same unit such as inches.

   $x \text{ in} = 3.12 \text{ ft} \left(\frac{12 \text{ in}}{1 \text{ ft}}\right) = 37.4 \text{ in}$

   $x \text{ in} = 0.0455 \text{ yd} \left(\frac{3 \text{ ft}}{1 \text{ yd}}\right)\left(\frac{12 \text{ in}}{1 \text{ ft}}\right) = 1.64 \text{ in}$

   $V = 37.4 \text{ in x } 1.64 \text{ in x } 7.87 \text{ in} = 483 \text{ in}^3$

   Note the question is asking for cm^3. We know the conversion from in to cm. We can easily convert in^3 to cm^3 thus:

   $$\left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)^3 = \left(\frac{2.54^3 \text{ cm}^3}{1 \text{ in}^3}\right)$$

   Thus, we can convert 483 in^3 into cm^3 as follows:

   $x \text{ cm}^3 = 483 \text{ in}^3 \left(\frac{2.54^3 \text{cm}^3}{1 \text{ in}^3}\right) = 7.91 \text{ x } 10^3 \text{ cm}^3$

8. $x \text{ mm}^3 = 0.2587 \text{ ft}^3 \left(\frac{12^3 \text{ in}^3}{1 \text{ ft}^3}\right)\left(\frac{2.54^3 \text{ cm}^3}{1 \text{ in}^3}\right)\left(\frac{10^3 \text{ mm}^3}{1 \text{ cm}^3}\right) = 7.326 \text{ x } 10^6 \text{ mm}^3$

9. $x \frac{\text{nm}}{\text{s}} = \frac{55 \text{ mi}}{1 \text{ h}}\left(\frac{5280 \text{ ft}}{1 \text{ mi}}\right)\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)\left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)\left(\frac{10^7 \text{ nm}}{1 \text{ cm}}\right)\left(\frac{1 \text{ h}}{60 \text{ min}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 2.5 \text{ x } 10^{10} \text{ nm/s}$

10. $x \frac{\text{g}}{\text{mL}} = \left(\frac{2.87\text{x}10^{-4} \text{ lb}}{1 \text{ in}^3}\right)\left(\frac{454 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1 \text{ in}^3}{2.54^3 \text{ cm}^3}\right)\left(\frac{1 \text{ cm}^3}{1 \text{ mL}}\right) = 7.95\text{x}10^{-3} \text{ g/mL}$

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Below is an abstract from my research for your review. If you have any further questions feel free to contact me either via email or by phone 225-XXX-XXXX.

Thank you for your time and consideration.

Jennifer Ellis

Abstract

This study was designed to evaluate the effects of the proprietary software, “Conversionoes,” on students' conceptual and visual understanding of dimensional analysis. The participants in the study were high school general chemistry students enrolled in two public high schools with different demographics (School A and School B) in the Chattanooga, Tennessee, metropolitan area. Using a “treatment group” and a “control group (no treatment), a mixed methods design was used in the data collection and analysis to provide a holistic view of the impact of the software on student learning. The resulting qualitative and quantitative data confirmed that the Conversionoes software enhanced the treatment groups’ conceptual and visual understanding of dimensional analysis. In fact, when all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. This was verified by the quantitative data, which indicated a significant difference between the overall pre-test and post-test scores at School A and School B ($p = 0.027$, $p = 0.028$, respectively). The qualitative data showed that students valued their experiences using the Conversionoes software and were able to enhance their knowledge of all aspects of dimensional analysis.

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Your topic looks fascinating and I wish you the best upon its submission!

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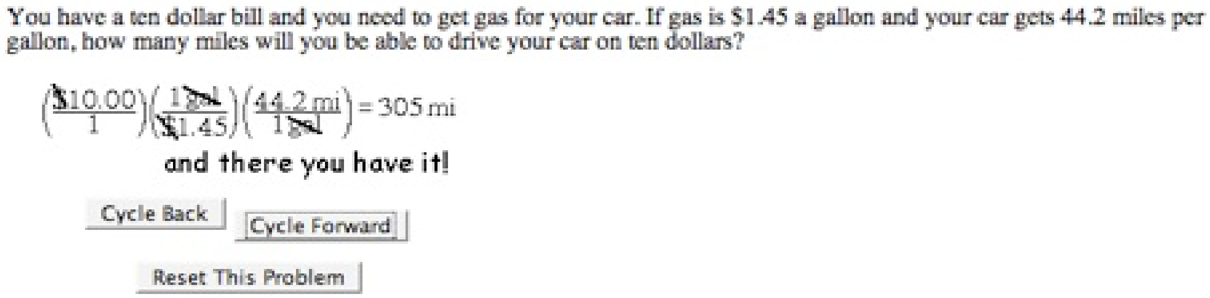

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Thank you for your time and consideration.

Jennifer Ellis

Abstract

This study was designed to evaluate the effects of the proprietary software, "Conversionoes," on students' conceptual and visual understanding of dimensional analysis. The participants in the study were high school general chemistry students enrolled in two public high schools with different demographics (School A and School B) in the Chattanooga, Tennessee, metropolitan area. Using a "treatment group" and a "control group (no treatment), a mixed methods design was used in the data collection and analysis to provide a holistic view of the impact of the software on student learning. The resulting qualitative and quantitative data confirmed that the Conversionoes software enhanced the treatment groups' conceptual and visual understanding of dimensional analysis. In fact, when all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. This was verified by the quantitative data, which indicated a significant difference between the overall pre-test and post-test scores at School A and School B ($p = 0.027$, $p = 0.028$, respectively). The qualitative data showed that students valued their experiences using the Conversionoes software and were able to enhance their knowledge of all aspects of dimensional analysis.

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Publisher: Other:Author/Editor: Gilbert, Kirss, and Davies
ISBN:
Title: Dimensional Analysis
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Author/Editor Jennifer Tennille Pinder Ellis
Publisher Louisiana State University
Publication Date: September 21, 2009
Publication Format: Other: Number of Pages: 260
Amount of First Print Run: 6 (for committee members)
Price: $0
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Renee Moilanen
Port of Long Beach
925 Harbor Plaza
Long Beach, CA 90802
Ph. (562) 901-1773
Cell (562) 708-2698
Fax: (562) 901-1735

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Below is an abstract from my research for your review. If you have any further questions feel free to contact me either via email or by phone 225-XXX-XXXX.

Thank you for your time and consideration.

Jennifer Ellis

Abstract

This study was designed to evaluate the effects of the proprietary software, “Conversionoes,” on students' conceptual and visual understanding of dimensional analysis. The participants in the study were high school general chemistry students enrolled in two public high schools with different demographics (School A and School B) in the Chattanooga, Tennessee, metropolitan area. Using a “treatment group” and a “control group” (no treatment), a mixed methods design was used in the data collection and analysis to provide a holistic view of the impact of the software on student learning. The resulting qualitative and quantitative data confirmed that the Conversionoes software enhanced the treatment groups’ conceptual and visual understanding of dimensional analysis. In fact, when all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. This was verified by the quantitative data, which indicated a significant difference between the overall pre-test and post-test scores at School A and School B ($p = 0.027$, $p = 0.028$, respectively). The qualitative data showed that students valued their experiences using the Conversionoes software and were able to enhance their knowledge of all aspects of dimensional analysis.

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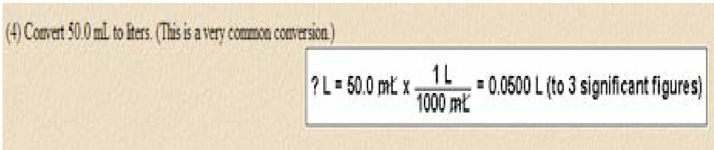

Figure 16 . Example of a common conversion problem student's will solve in general chemistry.

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APPENDIX AW: PRE- AND POST-TEST EXCEL RAW DATA

School A

Control	PreTest	PostTest	Percent Increase	Ethnicity/Gender
1	17.00%	17.00%	0.00%	WF
1	5.67%	11.00%	5.33%	WF
1	11.00%	0.00%	-11.00%	AAF
1	11.00%	5.67%	-5.33%	AAM
1	11.00%	17.00%	6.00%	WF
1	17.00%	5.67%	-11.33%	WM
1	5.67%	5.67%	0.00%	AAM
1	5.67%	5.67%	0.00%	WM
Avg	**10.50%**	**8.46%**	**-2.04%**	

Treatment	PreTest	PostTest	Percent Increase	Ethnicity/Gender
2	5.67%	17.00%	11.33%	WM
2	17.00%	33.00%	16.00%	AAF
2	17.00%	33.00%	16.00%	AAF
2	11.00%	29.00%	18.00%	AAM
2	11.00%	11.00%	0.00%	WM
2	5.67%	25.00%	19.33%	WM
2	5.67%	25.00%	19.33%	WF
2	5.67%	5.67%	0.00%	WF
Avg	**9.84%**	**22.33%**	**12.50%**	

	PreTest	PostTest
Control	10.50%	8.46%
Treatment	9.84%	22.33%

Ethnicity
WM AVG
10.22%
WF AVG
9.67%
AAM AVG
18.00%
AAF AVG
16.00%

School B

Control	PreTest	PostTest	Percent Increase	Ethnicity/Gender
1	22.00%	16.70%	-5.30%	WM
1	28.00%	22.00%	-6.00%	WF
1	28.00%	16.70%	-11.30%	WM
1	22.00%	11.00%	-11.00%	WF
1	16.70%	11.00%	-5.70%	WF
1	5.67%	56.70%	51.03%	WM
Avg	**20.40%**	**22.35%**	**1.96%**	

Treatment	PreTest	PostTest	Percent Increase	Ethnicity/Gender
2	28.00%	33.00%	5.00%	WM
2	28.00%	33.00%	5.00%	WF
2	22.00%	33.00%	11.00%	WF
2	22.00%	33.00%	11.00%	WM
2	22.00%	33.00%	11.00%	WM
2	22.00%	67.00%	45.00%	WF
Avg	**24.00%**	**38.67%**	**14.67%**	

	PreTest	PostTest
Control	20.40%	22.35%
Treatment	24.00%	38.67%

School B Gender	Overall Gender
WM AVG	Males Avg
7.41%	12.42%
WF AVG	Females Avg
20.37%	15.59%

VITA

Jennifer Tennille Pinder Ellis was born in Columbia, Maryland, and was raised in Somerset, New Jersey. She received her Bachelor of Science degree in chemical engineering from Tuskegee University in Tuskegee, Alabama. Immediately after graduating she served as an intern for the DuPont Center of Collaborative Research and Education where the idea was planted that she could use her chemical engineering knowledge in an unconventional way. After working eight months at DuPont she began her graduate studies at the University of Michigan in Ann Arbor, Michigan, where she received her Master of Science degree in information.

After completing her studies at the University of Michigan, Jennifer started her professional career working as an explosive engineer for the United States Army. In this position she was able to apply her chemical engineering knowledge as well as her information skills to help improve weapon systems. Although she was on a fast track as a civil servant she felt that her talents could be better utilized helping minority students improve their proficiency in science, technology, engineering and mathematics (STEM) education. She felt the best way for her to accomplish this goal was to pursue doctoral studies in science education. Jennifer enrolled in a doctoral program at Louisiana State University in the Fall of 2005. Her specific research interest focused on enhancing STEM teaching, learning and assessment via educational technology. Her dissertation revolved around the effectiveness of software she created to enhance student learning of dimensional analysis. The degree of Doctor of Philosophy will be conferred at the December 2009 commencement ceremony.

Jennifer is married to Eynus Cane Ellis. She is the daughter of Alfredy and Rosemary Pinder and the older sister to Erin Leigh Pinder. She is also the daughter-in-law of Ella Mae Thompson and the sister-in-law of Evangeline and Kenderick.